PB80-158710

Transportation Air Quality Analysis
Sketch Planning Methods
Volume II: Case Studies

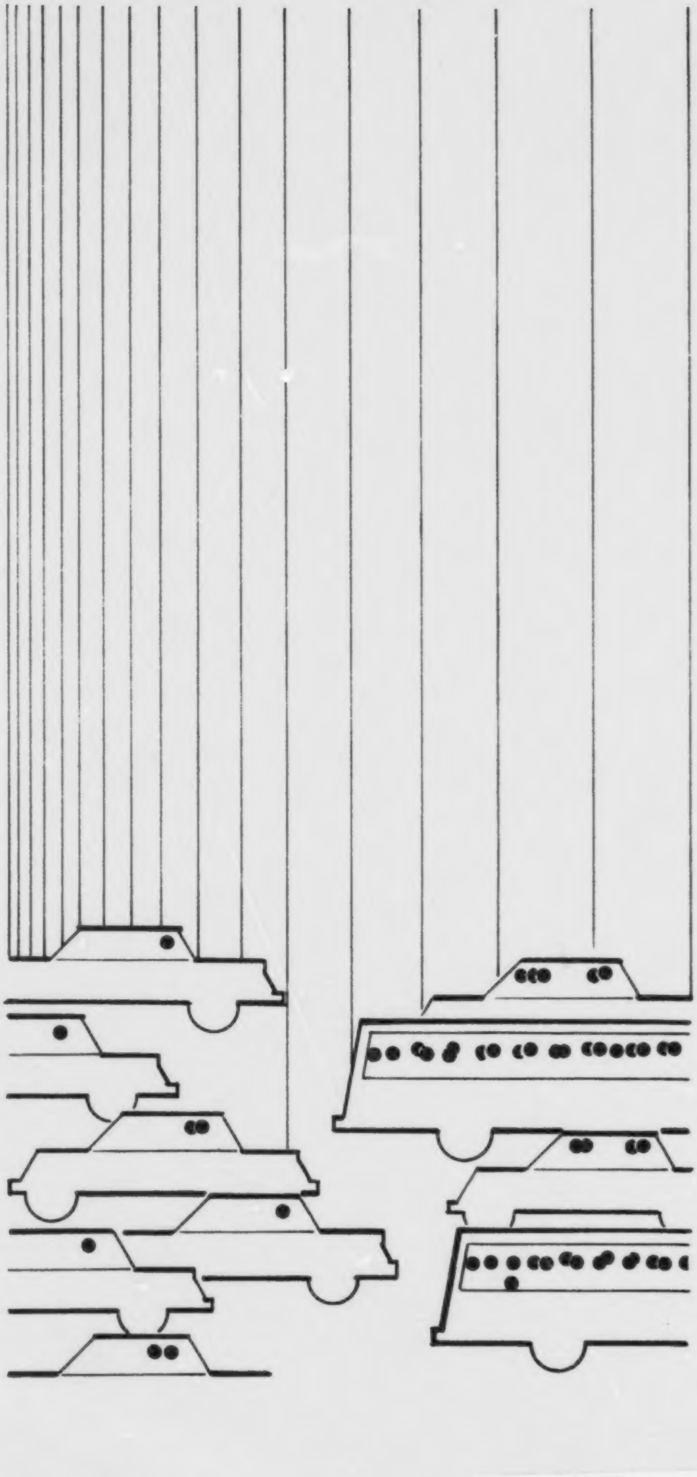
Cambridge Systematics, Inc, MA

Prepared for

Environmental Protection Agency, Washington, DC
Office Transportation and Land Use Policy

Dec 79

PB80-158710



transportation air quality analysis

sketch planning methods

Volume II

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This information document is isssued by the Office of Transportation and Land Use Policy, U.S. Environmental Protection Agency, in response to Section 108(f) of the Clean Air Act. This document provides a range of quantitative analytical techniques to evaluate transportation measures and packages of alternative measures, and is designed to assist State and local air pollution control agencies and Section 174 lead planning agencies to perform transportation-air quality planning. Although examples are provided, this document is not intended as a substitute for the necessary case-by-case analysis by approporiate local planning organizations.

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Technical Report Documentation Page

1. Report No. EPA 400/1-800-001b

2. Government Accession No.

3. Recipient's Catalog No.

4. Title and Subtitle

TRANSPORTATION AIR QUALITY ANALYSIS -
SKETCH PLANNING METHODS
Volume II: Case Studies

5. Report Date December, 1979

6. Performing Organization Code 78015

7. Author(s)

8. Performing Organization Report No.

9. Performing Organization Name and Address

Cambridge Systematics, Inc.
238 Main Street
Cambridge, Massachusetts 02142

10. Work Unit No. (TRAIS)

11. Contract or Grant No. 68-01-4977

12. Sponsoring Agency Name and Address

Office of Transportation & Land Use Policy
Environmental Protection Agency
401 M Street S.W.
Washington, D.C. 20460

13. Type of Report and Period Covered Final Report

14. Sponsoring Agency Code

15. Supplementary Notes

Part of a two-volume final report describing sketch planning methods for transportation and air quality planning.

16. Abstract

Analytical methodologies are described (in Volume 1) and illustrated (in Volume II) for use by metropolitan planning organizations and other state and local transportation agencies in analyzing the air quality potential of candidate urban transportation measures. As sketch planning techniques, the methods are designed to produce first-cut estimates of a proposed transportation measure's impact for a relatively small investment of time and effort. Quantitative methods oriented to auto restricted zones, high occupancy vehicle priorities, transit improvements, parking programs, carpool/vanpool incentives, and staggered work hours are provided. The methods use worksheet, programmable calculator, and computerized approaches to apply disaggregate behavioral models. They can be used to predict traveller demand as a function of transportation system characteristics, transportation facility operations as a function of their usage and their physical characteristics, and special impacts including vehicular emissions, fuel consumption, and operating costs. Guidelines are provided both to those responsible for designing the transportation-air quality analysis approaches in specific local areas, and to those who will carry out these analyses. In addition, references are provided to documents which provide additional detail on the methods.

17. Key Words

Air Quality Planning
Urban Transportation Planning
Sketch Planning
Transportation Systems Management

18. Distribution Statement

19. Security Classif. (of this report) unclassified

20. Security Classif. (of this page) unclassified

21. No. of Pages

22. Price

Form DOT F 1700.7 (8-72)

Reproduction of completed page authorized

EPA 400/1-80-001b EPA Contract No. 68-01-4977

TRANSPORTATION AIR QUALITY ANALYSIS SKETCH PLANNING METHODS

VOLUME II

DECEMBER 1979

Prepared for:

Environmental Protection Agency
Office of Transportation and Land Use Policy
in Cooperation with the
Urban Mass Transportation Administration
Office of Planning Methods and Support

PREFACE

The sketch planning methods described in this handbook have been assembled and illustrated under contract to the U.S. Environmental Protection Agency and the Urban Mass Transportation Administration in order to provide assistance to local transportation agencies as they conduct the planning and analyses required to develop the transportation portions of State Implementation Plans. The handbook is presented in two volumes:

Volume I: Analysis Methods
Volume II: Case Studies

The project was performed by Cambridge Systematics, Inc. Earl R. Ruiter, Project Manager, and John H. Suhrbier, Principal Responsible, provided the overall direction and management of the work performed. The development of the handbook benefited greatly from the advice provided by Marvin L. Manheim in the sketch planning applications of transportation analysis and programmable calculator methods areas, and by Adolph D. May (University of California, Berkeley), and Frederick A. Wagner (Wagner-McGee, Inc.) in the area of highway facility operations. The development or enhancement of specific analysis methods was carried out by Ellyn S. Eder and Melissa M. Laube. Additional major contributors to the handbook were Elizabeth A. Deakin, Lance A. Neumann, Daniel S. Nagin, Terry J Atherton, Scott D. Nason, William D. Byrne, and Greig Harvey.

Important contributions have been made by EPA staff members Chris Shaver, David Levinsohn, Gary Hawthorn, and Joseph Ossi. Their support and individual inputs have been very much appreciated. The contents of this report, however, reflect the views of Cambridge Systematics, Inc., and they are fully responsible for the facts, the accuracy of the data, and the conclusions expressed herein. The contents should not be interpreted as necessarily representing the views, opinions, or policies of the Environmental Protection Agency, the Urban Mass Transportation Administration, or the United States Government.

TABLE OF CONTENTS

Page

INTRODUCTION

A. Purpose of this Handbook i- 1
B. The Range of Sketch Planning Techniques Available i- 5
C. General Structure of the Case Studies i- 7

CASE STUDY I: FREEWAY FACILITY RESERVED FOR CARPOOLS AND BUSES

A. Problem Presentation I- 1
B. Proposed Transportation Measures I- 1
C. Selection of Analysis Techniques I- 3
D. Overview of the Analysis I- 4
E. Defining the Scope of the Analysis I- 7
F. Input Data Development I- 9
G. Description of Model Application I-36
H. Impact Assessment I-38
I. Interpretation of Results I-51

CASE STUDY II: DOWNTOWN AUTO RESTRICTED ZONE

A. Problem Presentation II- 1
B. Proposed Transportation Measures II- 1
C. Selection of Analysis Technique II- 4
D. Overview of the Analysis II- 5
E. Defining the Scope of the Analysis II- 7
F. Input Data Development II- 8
G. Description of Model Application II-22
H. Impact Assessment II-41
I. Interpretation of Results II-51

CASE STUDY III: BUS PRIORITY STRATEGIES FOR A RADIAL URBAN CORRIDOR

A. Problem Presentation III- 1
B. Proposed Transportation Measures III- 3
C. Selection of Analysis Technique III- 3

LIST OF TABLES

		Page
I- 1	Detailed Trip Generation Characteristics	I-12
I- 2	Trip Generation Parameters	I-14
III-1	Tract and Block Input Data from "Block Statistics" Boston Urban Area	III-10
III-2	Tract Income Data from Census Tracts, Boston, SMSA	III-11
III-3	Tract Auto Ownership Data from census Tracts, Boston SMSA	III-12
III-4	Station Characteristics	III-23
III-5	Line Segment Characteristics	III-24
III-6	Intersection Characteristics	III-24
III-7	Equilibrium Transit Travel Times under Alternative Policies	III-55
III-8	Equilibrium Transit Ridership under Alternative Policies	III-55
III-9	Impacts Under Alternative Policies	III-59
III-10	Bus Emissions of Major Pollutants under Alternative Policies	III-63
III-11	Estimated Auto and Bus Emissions Impacts	III-69

IV-1 Estimated versus Adjusted Values of Alternative Specific Constant Terms IV- 1

IV-2 Changes in Travel Behavior and Travel-Related Impacts IV-12

IV-3 Percent Changes in Travel Behavior and Travel-Related Impacts of Ridesharing Promotion IV-15

IV-4 Changes in Travel Behavior and Travel-Related Impacts (A) IV-18

IV-5 Changes in Travel Behavior and Travel-Related Impacts (B) IV-21

V-1 Representative Trips for the Busway Option V-10

V-2 Subzone Percentages Busway Network V-12

V-3 Level of Service Assumptions V-14

V-4 Impact Summary for Busway Transit Option V-26

VII-1 Peak Period Travel Times VII-11

VII-2 Traffic Signal Timing Optimization Impacts VII-16

VII-3 Impacts of Traffic Signal Master Control Improvements VII-17

VII-4 Freeway Ramp Control System Impacts on Average Speed VII-20

VII-5 Freeway Ramp Control System Impacts on Proportion of Freeway Minute-Miles Congested VII-21

VII-6 Worksheet for Steps 1-6, Work Travel VII-23

VII-7 Travel Time Elasticities VII-26

VII-8 Worksheet for Steps 1-13, Work Travel VII-30

VII-9 Worksheet for Steps 1-13, Non-Work Travel VII-31

VII-10 Summary of Impacts of Combined Traffic Engineering Actions VII-32

LIST OF FIGURES

		Page
I- 1	Basic Steps for HOV Lane Analysis	I- 5
I- 2	Information Flow in Manual VMT Worksheet Analysis	I- 6
I- 3	Auto Ownership Distribution	I-10
I- 4	Study Corridor and Proposed HOV Lanes	I-17
I- 5	Freeway/Arterial Diversion Curves	I-26
II-1	Steps in Analysis of ARZ Policy Scenarios	II- 6
II-2	Auto Ownership Distribution	II-10
II-3	CBD Entry and Destination Zones	II-18
III-1	Study Corridor with Residential Analysis Zones	III- 2
III-2	Integrated Analysis Steps and Programs	III- 6
III-3	Sample HHGEN Worksheet	III-13
III-4	Generated Household Characteristics	III-16
III-5	Datasheet (2MODE-AGG)	III-20
III-6	Simplified Bus Route Representation	III-21
III-7	Base Case Equilibrium Data Flows	III-25
III-8	User Worksheet-Binary Mode Choice with Aggregation (2MODE-AGG)	III-27
III-9	Datasheet (2MODE-AGG)	III-29

III-10 User Instructions - Bus Route Simulation III-32

III-11 Worksheet C-1 Base Data III-46

III-12 Worksheet C-2 Changes in Transportation Level of Service III-47

III-13 Worksheet C-4 Program Steps III-48

III-14 Equilibrium Data Flows for Testing Effects of Transportation Measures III-54

III-15 User Worksheet - Energy Consumption on Bus Route III-57

III-16 User Worksheet - Bus Pollutant Emissions III-60

IV-1 SRGP Data Preparation Steps IV- 4

IV-2 Effectiveness of Combining Incentive and Disincentive Measures IV-23

V-1 Busway Network V- 2

V-2 Major Steps in Sketch Planning Procedure V- 5

V-3 1987 Transit Zones V- 7

V-4 System Description Log Sheet V- 9

V-5 Basic Level-of-Service Coding V-15

V-6 Mapping Matrix V-17

V-7 Work Mode Choice Sheet V-18

V-8 Non-Work Mode Choice Sheet V-18

V-9 Peak Period Operating Cost Sheet V-21

V-10 System Capital Costing Sheet V-23

V-11 Environmental Impacts Sheet V-24

VI-1 Location of Eastshore Freeway Corridor VI- 2

VI-2 Detailed Corridor Map VI- 3

VI-3 Eastshore Freeway Facility Data VI- 6

VI-4 Sample Origin-Destination Data for Eastshore Freeway--Time Slice One VI- 8

VI-5 Distribution of Passenger Occupancies on the Eastshore Freeway VI-10

VI-6 San Pablo Avenue Facility Data VI-11

VI-7 Queueing Diagram of Freeway Congestion before Entry Control VI-13

VI-8 Eastshore Freeway--Freeway Summary before Entry Control VI-15

VI-9 Eastshore Freeway--Arterial Summary before Entry Control VI-16

VI-10 Eastshore Freeway Ramp Control Summary: No Bypass Priority Ramp Lanes, No Diversion VI-18

VI-11 Eastshore Freeway Differential Effects: Entry Control without Bypass Priority Ramp Lanes, No Diversion VI-20

VI-12 Effects of Short- and Longer-term Diversion for Ramp Control without Priority Entry VI-21

VI-13 Eastshore Freeway Ramp Control Summary: Priority Ramp Bypass for Vehicles with Three or More Occupants, No Diversion VI-23

VI-14 Effects of Ramp Control with Priority Entry for Vehicles with Three or More Occupants VI-24

VI-15 Effects of Ramp Control after Diversion and Modal Shift with Priority Entry for Vehicles with Two or More Occupants VI-25

INTRODUCTION

A. Purpose of this Handbook

This handbook presents case studies illustrating the application of a selection of techniques for transportation-air quality planning. The emphasis is on "sketch planning" techniques--ones which can produce a first-cut estimate of a proposed transportation measure's impact for a relatively small investment of time and effort.

The analysis approaches illustrated here should be useful in developing the transportation portions of State Implementation Plans (SIP's), as required to meet national ambient air quality standards under the Clean Air Act, as amended (42 U.S.C. 1857 *et seq.*). The Act, and the joint Environmental Protection Agency/Department of Transportation guidelines issued pursuant to it, call for the analysis of a number of transportation measures which potentially could improve air quality (Table 1). The effects these measures would have--on travel; the transportation system; energy conservation; and a host of other social, environmental, economic, and financial concerns; as well as on air quality--must be evaluated within a broadly participatory, interactive planning process. Furthermore, the analyses must be completed expeditiously, in order to meet legislative deadlines for SIP adoptions and submittals. These combined requirements necessitate analytic capabilities which produce results quickly and yet provide accurate information on a wide range of impacts.

TABLE 1

Reasonably Available Transportation-Air Quality Measures to be Analyzed for SIP Revisions[1]

Transportation System Measures:

- improved public transit (short- and long-range)
- exclusive bus and carpool lanes
- area-wide carpool programs
- private car restrictions
- on-street parking controls
- pedestrian malls
- park-and-ride and fringe parking lots
- employer programs to encourage carpooling and vanpooling, mass transit, bicycling and walking
- bicycle lanes and storage facilities
- staggered work hours (flexitime)
- road pricing to discourage single-occupancy auto trips
- traffic flow improvements

Vehicle and Equipment Measures:

- inspection and maintenance programs
- alternative fuels or engines and other fleet vehicle controls
- other than light duty vehicle retrofit
- extreme cold start emission reduction programs
- controls on extended vehicle idling
- vapor recovery

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[1] Note: This report focuses on the first category of measures, those affecting the transportation system. The second catgory of measures are considered in some of the emissions estimation techniques, however.

Metropolitan Planning Organizations (MPO's) for the most part are taking the lead in transportation-air quality analysis. Often, however, the MPOs' analytical techniques center around large computer modelling systems which originally were designed to investigate the effects of long-term activity shifts and/or major capital investments in transportation. Such model systems tend to be too costly, too data-demanding, and too time consuming for use in analyzing the numerous alternatives to be considered in transportation-air quality planning. Because the models were not intended for analysis of transportation operations, management policies, or small changes in facilities, they often omit variables necessary to study such measures. Some of the variables which are included enter the models in ways that cannot respond to the influence of proposed actions, or that can do so only by recoding or reprogramming. Because the models were meant for regional studies, they frequently are so "aggregate" (i.e., coarse-scaled) that small or localized change cannot be discerned. The models usually do not have the capability to focus on a subarea or corridor except after considerable modification, and then only with a great deal of work. They rarely distinguish among various socioeconomic groups or other population subsamples. Thus, the conventional model systems are not well-suited for transportation-air quality planning--nor for most transportation system management (TSM) or transportation-energy conservation planning efforts, which likewise emphasize quick response analysis of management and operations policies and small capital investment projects. Methods which are cheaper, quicker, more flexible, and more responsive are needed.

In recent years, a number of sketch planning tools have been developed. They range from specialized techniques designed to address a particular type of measure or impact to general-purpose procedures and methodologies, and they cover a smililarly broad range of sophistication and complexity. In Volume I of this handbook, a selection of these sketch planning tools is reviewed, their applicability to various analysis problems is evaluated, and the resource requirements for each technique are assessed. Special emphasis is given to techniques suitable for transportation-air quality analysis, although most of the methods are more generally applicable to transportation system management planning and transportation energy conservation planning.

This handbook is designed with two major types of readers in mind:

- Those who are designing transportation-air quality analysis approaches, and in doing so must select an appropriate set of analysis techniques.
- Those who are conducting transportation-air quality analyses, and require reference material on particular analysis methods.

Volumes I and II both contain material useful to each of these types of readers. Volume I includes a discussion of the terminology used in the handbook, overviews of various kinds of analysis methods, descriptions of specific methods, pointers to further reference material, and analysis design issues. The case studies included in this volume provide extended examples of specific analysis methods. These examples will be useful to designers of analysis approaches in understanding the applicability of the methods, and to those carrying out these approaches in understanding the steps which must be carried out as specific methods are used.

B. The Range of Sketch Planning Techniques Available

Numerous sketch planning techniques have been developed in recent years. Three categories of such techniques are presented in this handbook:

- Travel demand analysis methods are those which predict traveller behavior in response to change in the transportation system. Techniques for trip generation, destination choice, mode share, and route choice are all reviewed.
- Facility operations analysis methods predict the operating characteristics of transportation facilities as a function of changes in capacity and operating policy. Intersection improvements, signal timing, capacity changes, and flow metering all are addressed by the techniques discussed.
- Special impact analysis methods focus on particular effects of transportation changes. Methods for assessing changes in vehicular emissions and fuel consumption are presented.

Within these categories, the techniques are further classified by the technology used in applying them:

- Manual methods are techniques which utilize worksheets, formulas, nomographs and the like to carry out hand calculations, as well as approaches for making use of data or study results from other urban areas.
- Programmable calculator methods are adaptations of manual methods which, by capitalizing on recent developments in inexpensive calculating equipment, allow for more detailed and precise analysis at no significant increase in effort.
- Computer-based methods are model systems for which time and expense are minimized by making simplifying assumptions or otherwise limiting the scope of the analysis.

Table 2 illustrates how the classification is used in this handbook. The methods were selected as representatives of the range of approaches which have been developed. The various techniques can accommodate different amounts and types of data, can be used at different levels of detail, and require various levels of staff expertise or experience,

TABLE 2

Typology of Sketch Planning Techniques

Technology	Demand	Facility Operations	Special Impacts
Manual	worksheet mode choice quick response urban travel estimation techniques systematic data analysis	traffic flow formulae graphical techniques areawide traffic engineering method transfer of experience	emissions worksheets auto fuel consumption and operating costs
Programmable Calculator	HHGEN 2MODE-AGG 3MODE(VAN)-AGG	BUS	BUSPOL ENERGY
Computer	CAPM SRGP transit sketch planning procedure	TRANSYT FREQ	MOBILE1

labor, and other resources. Furthermore, techniques which are applicable to the full range of transportation-air quality measures have been included. The handbook thus should be useful in disparate settings and under disparate conditions.

An index to the methods listed in Table 2 is provided in Table 3. This table shows the case studies in this volume in which the various methods are demonstrated, as well as the policies illustrated in each case study. Also, for each general class of method, and for each individual method, the appropriate section in Volume I in which it is discussed is indicated.

To illustrate the use of Table 3, consider first the analyst who wishes to see examples of the analysis of parking programs. Under this column, both Case Studies I and IV appear. Case Study I illustrates a number of manual demand and impact methods, and Case Study IV illustrates SRGP, a computer demand method. Secondly, consider an analyst who wishes to obtain information on calculator demand methods. The table provides Volume I section references to the general overview of this class of methods (2.2), and to the three methods described in detail in this handbook (2.2.1, 2.2.2, 2.2.3). The table also shows that two case studies (II and III) illustrate the use of these methods.

C. General Structure of the Case Studies

The remainder of this volume consists of seven case studies drawn from previous work done by the authors of this handbook and others to illustrate the application of sketch planning analysis methods to transportation-air

TABLE 3

Cross-Reference Table for Analysis Methods and Case Studies

METHOD	VOL I SECTION	VOLUME II: CASE STUDIES BY POLICY CLASS							
		Auto Restricted Zones	HOV Priorities	Traffic Flow Improvements	Transit System Improvements	Parking Programs	Pricing Policies	Carpool/ Vanpool Incentives	Staggered Work Hours
Manual Demand	2.1								
Pivot Point Mode Choice	2.1.1		I		I	I		I	
Synthetic Mode Choice	2.1.1								
Quick Response Urban Travel Estimation	2.1.2		I		I	I		I	
Systematic Data Analysis	2.1.3	II	I	II	I,II	I		I	
Calculator Demand	2.2								
HHGEN - Household Samples	2.2.1		III		III				
2MODE-AGG - Synthetic Mode Choice	2.2.2		III		III				
3MODE(VAN)-AGG - Pivot Point Mode Choice	2.2.3	II	III	II	II,III				
Computer Demand	2.3								
CAPM - Community Aggregate Planning Model	2.3.1								
SRGP - Short-Range Generalized Policy Analysis	2.3.2				IV	IV		IV	
Transit Sketch Planning	2.3.3				V				
Manual Facility Operations	3.1								
Traffic Flow Formulae	3.1.1								
Graphical Techniques	3.1.2								
Areawide Traffic Engineering	3.1.3			VII					
Transfer of Experience	3.1.4								

TABLE 3 (Con't)

Cross-Reference Table for Analysis Methods and Case Studies

		VOLUME II: CASE STUDIES BY POLICY CLASS							
METHOD	VOL I SECTION	Auto Restricted Zones	HOV Priorities	Traffic Flow Improvements	Transit System Improvements	Parking Programs	Pricing Policies	Carpool/ Vanpool Incentives	Staggered Work Hours
Calculator Facility Operations	3.2								
BUS - Bus Operations	3.2.1		III		III				
Computer Facility Operations	3.3								
TRANSYT - Arterial Street Systems Analyzer	3.3.1								
FREQ - Freeway System Analyzer	3.3.2		VI	VI					
Manual Impacts	4.1								
Emissions Worksheets	4.1	II	I,III	II,VII	I,II,III	I		I	
Auto Fuel Consumption and Operating Costs	4.2	II		II	II				
Calculator Impacts	4.3								
BUSPOL/ENERGY - Bus Emissions and Fuel Consumption	4.3		III		III				
Computer Impacts	4.4								
MOBILE1 - Auto Emissions	4.4								

quality planning. A common structure is generally used to present each case study, with minor variations adopted where these are required. The sections included in the common structure are presented as subsections here, with a discussion of their functions. Also, the sections of Volume I which discuss more generally the issues or procedures addressed in the specific case study context are identified.

1. Problem Presentation

This section introduces the case study, discussing briefly the air quality problem which is addressed and its geographical, demographic, and transportation system contexts.

2. Proposed Transportation Measures

The nature of the transportation measures which are proposed as partial solutions of the air quality problem are discussed. The proposed new or modified transportation facilities and operational strategies are discussed, and their expected impacts on both travel patterns and air quality are identified.

3. Selection of Analysis Techniques

The analysis techniques used in the case study are identified, with references to their discussion in Volume I. Also, the reasons for selecting each technique are presented. General discussions of the analysis selection issue are included in Sections 1.4 and 5.1 of Volume I.

4. Overview of the Analysis

In cases where multiple techniques are illustrated, the major analysis steps are described and their relationships to each other are discussed. Section 5.1 of Volume I addresses this topic more generally.

5. Defining the Scope of the Analysis

This section presents a rationale for the market segmentation approach chosen for use in the analysis, as an example of the application of the guidelines presented in Section 5.3 of Volume I, and describes the criteria used to define each group of actual or potential travellers identified as a market segment.

6. Input Data Development

The all-important process of specifying the values of input variables for the chosen analysis methods is described. Data sources are identified, and alternative sources are mentioned as an aid to understanding how specific local data availability issues can be addressed. Section 5.2 of Volume I discusses general issues in representing transportation system changes, and Section 5.5 discusses alternative data sources more generally.

7. Description of Model Application

The step-by-step process of applying the chosen analysis techniques to evauate the proposed transportation measures is discussed. Where applicable, illustrative worksheets are included, completed to show the calculation process which was carried out. This section thus provides examples of the use of the methods presented in Chapters 2, 3, and 4 and of the worksheets included in Appendices A through E of Volume I.

8. Impact Assessment

This section summarizes the travel, air quality, and energy conservation impacts predicted for the proposed transportation measures.

9. Interpretation of Results

The results summarized in the former section are interpreted in terms of their significance, their impact on further analysis and implementation decisions, and their limitations due to the nature of the input data, scope of the analysis and applicability of the analysis methods. It should be noted that the results are only meant to illustrate the use of the sketch planning methods to evaluate a specific transportation-air quality problem in a specific geographic, demographic, and transportation context. The results should not be used as general evaluations of the proposed transportation measures or as indicative of the impacts to be expected if these measures are implemented in other contexts.

CASE STUDY I

FREEWAY FACILITY RESERVED FOR CARPOOLS AND BUSES

CASE STUDY I: FREEWAY FACILITY RESERVED FOR CARPOOLS AND BUSES

A. Problem Presentation

An urban area with population 1.5 million has serious violations of the health standard for ozone during the summer. Within the area is a travel corridor which includes a major radial freeway. This freeway generates 34,000 vehicle trips to the CBD and fringe areas of the central city during the morning peak period. One of the largest travel generators in the region, the corridor suffers from increasing congestion, particularly on the radial freeway. In addition to the congestion, major construction projects proposed for the downtown area are expected to cause delays to CBD-bound commuters from the corridor.

B. Proposed Transportation Measures

To help alleviate the increasing congestion and the air quality problems in the area, a plan incorporating two complementary actions has been proposed. The major feature of the proposal is the construction of a reversible two-lane facility on the median strip of the existing freeway. These lanes will provide peak direction flow for buses and carpools with four or more occupants. Expansion of bus services is also proposed to encourage the use of the high occupancy vehicle (HOV) lanes.

Due to the existing congestion on the freeway, significant time savings for the line-haul portion of the trips made by vehicles eligible to use the HOV lanes are expected. The project involves adding new lanes to the freeway, so congestion and travel times are not expected to increase for drive alone commuters and those in two and three person carpools, except those bound for the downtown area who will be delayed by the construction there.

Other factors are also expected to change the level of transportation service for trips in the corridor. As a result of a program to encourage carpooling, major employers in the fringe area (representing about half of the total employment in this area) are planning to offer preferred parking spaces to carpoolers. Single occupant auto drivers working at these employment sites should be inconvenienced to some degree. An additional measure intended to encourage the use of public transit in the corridor is the creation of special bus lanes in the downtown area, routed so as to avoid the construction-related delays to be experienced by autos.

It is argued that these measures will result in a shift by people living in the corridor and working in the central city from autos to buses, from single-occupant autos to carpools, and from two- and three- occupant autos to four-person and larger carpools. These shifts in mode usage should lead to decreases in VMT, vehicle trips, HC and NO_x emissions (which cause formation of ozone), and gasoline consumption in the corridor.

The direct impacts of the proposed measures on transportation levels of service in the corridor are as follows:

Change	LOS Impact
HOV Lanes	Reduced transit in-vehicle travel time (IVTT) to central city (fringe and CBD)
	Reduced IVTT for 4+ person carpools to central city
Construction	Increased IVTT for all autos to the CBD
Employer Parking Policy (Affects one-half of employees in the fringe area)	Increased out-of-vehicle travel time (OVTT) for drive alone trips to fringe areas
	Decreased OVTT for all carpools to fringe areas
Bus Frequency Improvements	Decreased OVTT for transit trips to the central city

The problem is to predict the magnitude of the vehicle emissions, fuel consumption, and other impacts of the proposed measures, given the set of expected LOS impacts. It is expected that the proposed measures will be completely in place by 1982, which has therefore been chosen as the analysis year.

C. Selection of Analysis Techniques

Because the proposed measures are in the early stages of planning and evaluation, a quick and somewhat gross estimate of the effects of the plan is desired to determine if further, more detailed analysis is justified. The limited resources available for this initial analysis dictate that manual techniques be used, drawing on existing sources of data to the maximum degree possible. For these reasons the manual pivot-point mode choice (2.1.1a)[1] and the emissions worksheets (4.1) methods are chosen for the analysis of the proposed transportation measures. In addition, portions of the quick response urban travel estimation (2.1.2) and systematic data analysis (2.1.3) techniques are used to specify base case conditions.

D. Overview of the Analysis

Seven major steps are involved in the application of the manual analysis techniques to the evaluation of the HOV lanes and accompanying measures:

Step 1 - Identify the effects of the HOV lane and other factors;

Step 2 - Segment the population into homogeneous subgroups;

Step 3 - Quantify existing mode splits for each sub-group;

Step 4 - Quantify the level-of-service changes for each sub-group;

Step 5 - Apply FEA VMT analysis worksheets to each subgroup;

Step 6 - Determine corridor-wide VMT and auto trip changes;

Step 7 - Determine corridor-wide emissions changes.

These steps are illustrated in Figure I-1. Information flows between steps are illustrated by arrows. Steps 5 and 6 involve the utilization of the FEA VMT analysis worksheets, while Step 7 involves the use of the manual emissions worksheets.

Figure I-2 illustrates the use of the manual pivot-point mode choice method in carrying out the analysis. Steps labelled with numbers indicate the use of specific worksheets. Worksheets I, II-A, II, V, and V-A are used only once. The remaining worksheets are used once for each popula-

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[1] The section numbers following specified analysis methods refer to the location of their description in Volume I. In addition, master copies of all worksheets used are provided in Appendices A and D of Volume I.

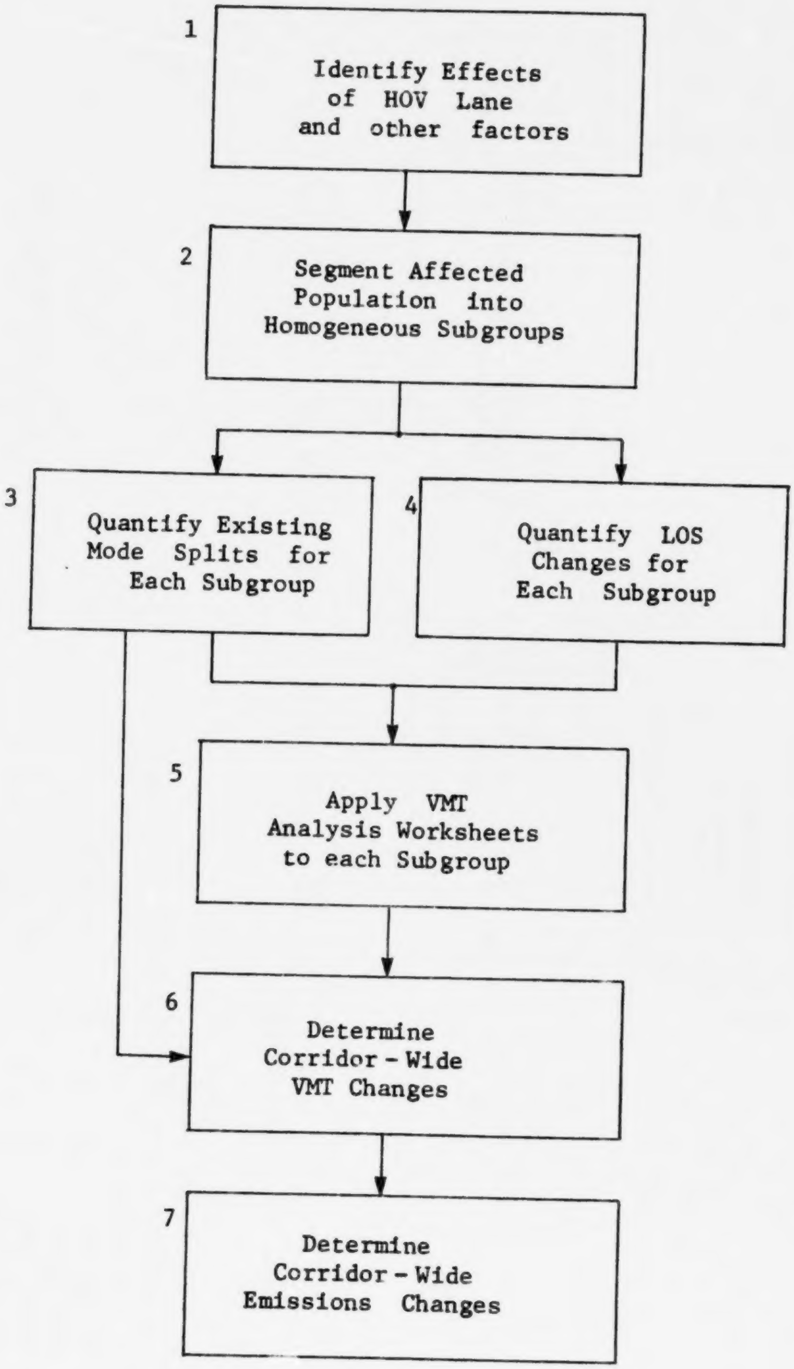
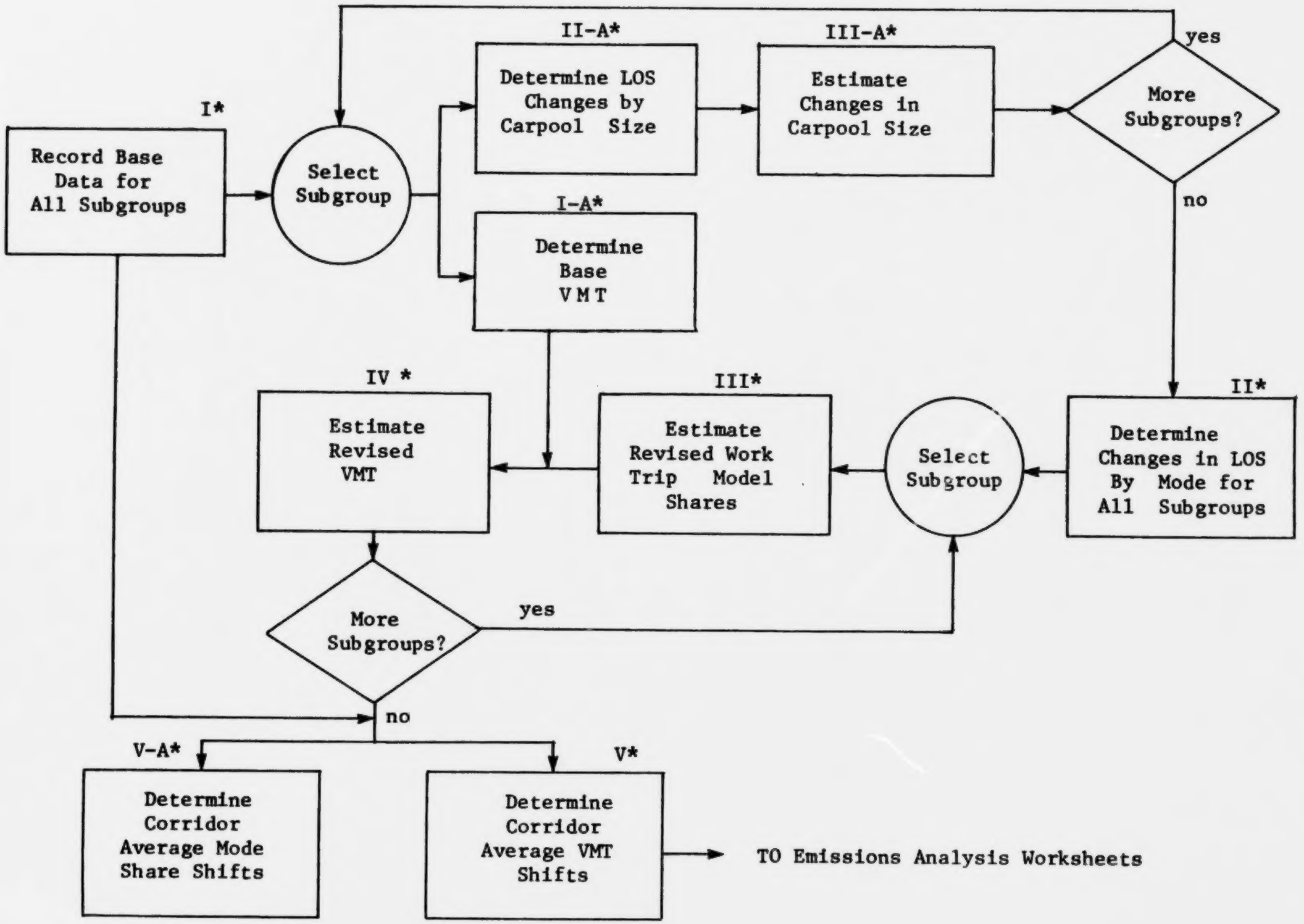

1
Identify Effects of HOV Lane and other factors
2
Segment Affected Population into Homogeneous Subgroups
3
Quantify Existing Mode Splits for Each Subgroup
4
Quantify LOS Changes for Each Subgroup
5
Apply VMT Analysis Worksheets to each Subgroup
6
Determine Corridor - Wide VMT Changes
7
Determine Corridor - Wide Emissions Changes

FIGURE I-1

Basic Steps for HOV Lane Analysis


I*
Record Base Data for All Subgroups
Select Subgroup
II-A*
Determine LOS Changes by Carpool Size
III-A*
Estimate Changes in Carpool Size
More Subgroups?
yes
no
I-A*
Determine Base VMT
II*
Determine Changes in LOS By Mode for All Subgroups
Select Subgroup
III*
Estimate Revised Work Trip Model Shares
IV *
Estimate Revised VMT
More Subgroups?
yes
no
V-A*
Determine Corridor Average Mode Share Shifts
V*
Determine Corridor Average VMT Shifts
TO Emissions Analysis Worksheets

*Worksheet number

FIGURE I-2

Information Flow in Manual VMT Worksheet Analysis tion subgroup to be analyzed. The following section describes the identification of population subgroups.

E. Defining The Scope of the Analysis

Steps 1 and 2 define the scope and level of detail of the analysis. The more effects identified and more subgroups considered, the more complex (and accurate) the analysis becomes. The major impacts of the proposed measures were outlined in Section B. These effects will be the only ones considered in this initial evaluation of the proposal.

The purpose of segmenting the affected population is to obtain a number of groups which face approximately the same changes in level-of-service, and which have the same set travel opportunities available to them. For example, under the proposed measures, commuters bound for the CBD will experience somewhat different impacts with respect to level-of-service than those bound for the fringe areas. For this reason, a classification of the corridor's commuters based on the location of their workplace is suggested.

Individuals not owning automobiles are likely to respond very differently to changes in the level-of-service of transportation modes than those who have one or more vehicles available for their use. Once again, a segmentation of the market is suggested, with auto-owning households being considered independently from those without autos available for their use. Those not owning autos are assumed not to have the drive alone mode available, but may use the transit or carpool modes. The population of the corridor is relatively homogeneous with respect to other characteristics, such as income, which are likely to affect travel behavior.

For this reason, no further segmentation of the population need be done for this analysis.

In situations where there is a great deal of variation within a population with respect to income, work trip length, current mode to work or trip-making behavior, a more extensive segmentation of the population would be useful. Also, if different types of change in transportation level-of-service will be experienced by certain groups (such as in the case of improved transit service targeted to low income areas within a city) the segmentation should be detailed enough to account for any differences which might lead to variations in travel behavior response. An additional consideration in the definition of market segments is the level of detail and accuracy desired for the analysis in relation to the budget available for preparing the input data and doing the calculations.

The four subgroups implied by the two levels of segmentation described above are:

I. CBD-bound with all modes available
II. CBD-bound without the drive-alone mode
III. Fringe area-bound with all modes available
IV. Fringe area-bound without the drive alone mode.

Vehicle and person-trip counts on the existing highway--taken yearly by the local traffic department--indicate that 60 percent of the trips originating on the corridor are bound for the CBD, while 40 percent are destined for the fringe area.

Income projections, developed as part of a land use study for the metropolitan area, indicate that the mean income (in 1970 dollars) for residents of the study corridor will be $11,000 in 1982. Because no projection of auto ownership levels is available, this income level must be used to estimate the distribution of households by auto ownership category for the corridor. Curves relating auto ownership level and income, grouped by urban area size category are available in the report, Trip Generation Analysis, prepared by FHWA.[1] The curve for Philadelphia, Pennsylvania was chosen for use in estimating auto ownership in the study corridor (See Figure I-3). This selection was based on the fact that the urban area under study, like Philadelphia, is an older eastern city with relatively good transit service. Reading the auto ownership levels for 1970 income level $11,000 yields: zero autos, 11.5 percent; one auto, 59.0 percent; two autos, 28.0 percent; three or more autos, 1.5 percent. The 11.5 percent zero-auto ownership level and the distribution of trips by destination imply the following distribution of households in the corridor by subgroup:

I. - 53.1%
II. - 6.9%
III. - 35.4%
IV. - 4.6%

These values are entered on column 2 of Worksheet I, Base Data.

This use of available data to assist in specifying the base case illustrates a systematic data analysis method (2.1.3).

F. Input Data Development

The input data required for the analysis are defined on Worksheets I, II-A, and II.

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[1] U.S. Department of Transportation, Federal Highway Administration; Trip Generation Analysis, August, 1975.

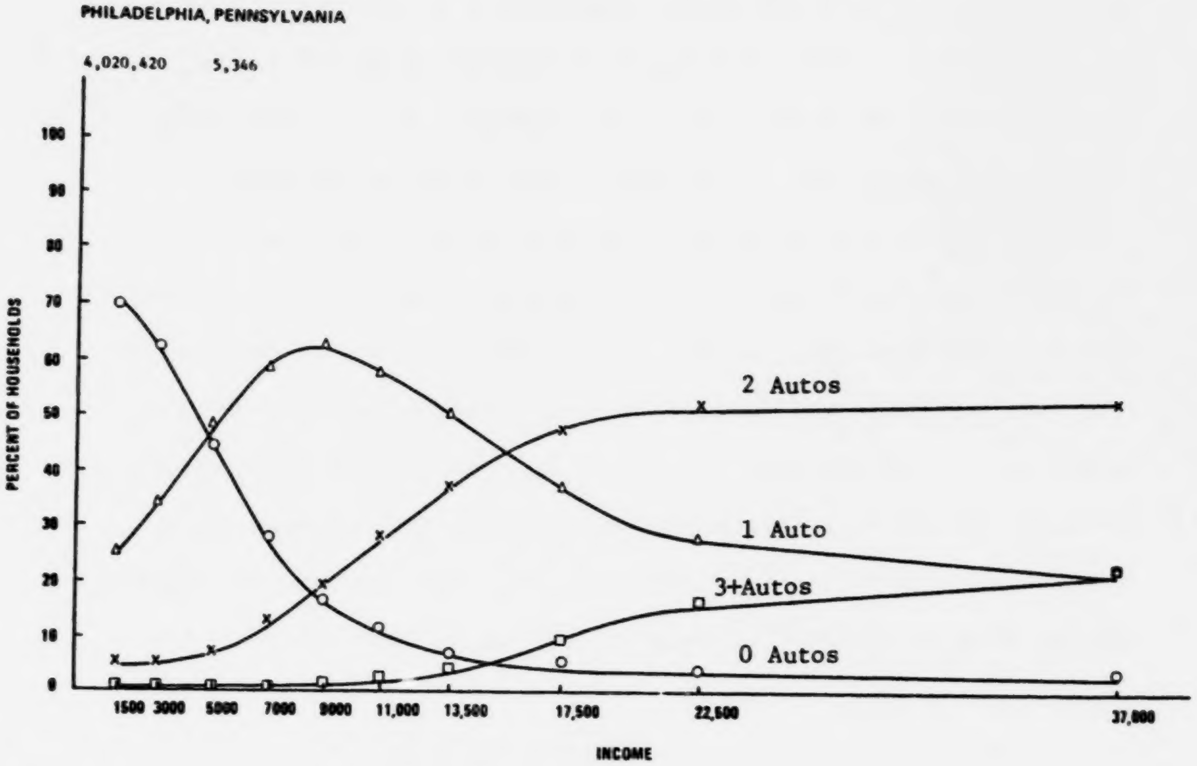

FIGURE I-3

Auto Ownership Distribution

Socioeconomic, mode choice, and tripmaking statistics are required by Worksheet I for each of the four market segments to be analyzed.

Typical sources for the types of data required include:

- Nomographic/formula techniques or other estimation procedures
- U.S. Census
- Recent or updated home interview surveys
- Traffic counts
- Transit ridership data
- Projections done in past years
- National average figures and relationships

Household Data

In this case, income projections based on past Census data were used to determine the average income for the corridor and the average number of workers per household (column 3 and 4) in 1982. No information on non-work tripmaking was available from the land use study which provided the projections, so a portion of the quick response urban travel estimation technique (2.1.2) was employed to estimate the non-work tripmaking behavior of the corridor's households. Table 2 of NCHRP Report 187[1] (repeated here as Table I-1) provides average tripmaking rates by urban area size, income range, and auto ownership level, as well as the typical distribution of number of autos owned for each income range and the percentage of trips by major purpose. For urban areas between 750,000 and 1,000,000 population, and the $10 - 12.5 thousand income range, the following information is presented:

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[1] Sosslau, et al., Comsis Corporation; Quick-Response Urban Travel Estimation Techniques and Transferable Parameters: Users Guide; NCHRP Report 187; 1978.

TABLE I-1

Detailed Trip Generation Characteristics

URBANIZED AREA POPULATION: 250,000-750,000

IncomeRange 1970 $ (000's)	Avg Autos Per HH[d]	Average Daily Person Trips per HH[e]	% HH by Autos Owned[b]				Average Daily Person Trips Per HH by No. of Autos/HH[c]				% Average Daily Person Trips by Purpose[f]		
			0	1	2	3+	0	1	2	3+	HBW	HBNW	NHB
0-3	0.47	3.3	58	37	5	0	1.4	5.6	9.3	9.3	10	67	23
3-4	0.77	5.8	38	50	10	2	2.0	7.4	10.8	11.1	13	64	23
4-5	0.88	6.9	29	57	12	2	2.5	8.0	11.5	11.9	21	57	22
5-6	1.01	8.4	20	62	16	2	2.9	9.0	12.1	12.7	22	56	22
6-7	1.10	9.5	14	65	19	2	3.5	9.7	12.7	13.5	22	55	23
7-8	1.24	10.9	8	64	25	3	4.0	10.6	13.5	14.4	20	55	25
8-9	1.33	11.7	6	60	30	4	4.6	11.0	14.2	15.3	20	55	25
9-10	1.40	12.4	4	57	35	4	5.2	11.2	14.8	16.2	20	55	25
10-12.5	1.58	13.5	2	46	46	6	5.5	11.3	15.6	17.6	20	55	25
12.5-15	1.72	14.6	2	36	53	9	5.5	11.4	16.4	18.8	20	53	27
15-20	1.88	15.5	2	26	58	14	5.2	11.5	16.7	19.1	20	52	28
20-25	2.04	16.0	1	20	59	20	5.0	12.0	16.7	18.6	20	50	30
25+	2.08	16.2	1	17	61	21	5.0	12.0	16.7	18.6	20	50	30
Wt. Avg.	1.41	11.8	12	44	37	7	4.3	10.0	14.4	15.8	20	55	25

URBANIZED AREA POPULATION: 750,000-2,000,000

IncomeRange 1970 $ (000's)	Avg Autos Per HH[d]	Average Daily Person Trips per HH[e]	% HH by Autos Owned[b]				Average Daily Person Trips Per HH by No. of Autos/HH[c]				% Average Daily Person Trips by Purpose[f]		
			0	1	2	3+	0	1	2	3+	HBW	HBNW	NHB
0-3	0.47	1.9	58	37	5	0	0.8	3.2	5.7	7.3	14	66	20
3-4	0.68	3.7	40	52	8	0	2.0	4.5	7.0	9.2	22	59	19
4-5	0.78	4.5	32	58	10	0	2.5	5.0	7.5	10.0	28	53	19
5-6	0.84	5.1	28	60	12	0	2.7	5.6	8.0	11.0	28	53	19
6-7	0.95	5.8	22	62	15	1	2.9	6.1	8.6	11.6	28	53	19
7-8	1.06	6.5	16	63	20	1	3.0	6.5	9.2	12.2	27	53	20
8-9	1.16	7.2	12	63	23	2	3.2	6.9	9.5	12.6	27	53	20
9-10	1.25	7.7	9	61	27	3	3.3	7.1	9.9	13.0	27	54	19
10-12.5	1.41	8.5	5	56	34	5	3.4	7.5	10.1	13.6	26	53	21
12.5-15	1.60	9.4	2	45	46	7	3.6	7.5	10.7	14.2	25	53	22
15-20	1.77	9.9	2	35	51	12	3.6	7.6	10.7	14.6	24	53	23
20-25	1.95	10.6	2	24	56	18	3.7	7.0	11.1	14.8	24	53	23
25+	2.02	11.0	2	20	58	20	4.0	7.0	11.3	14.8	23	54	23
Wt. Avg	1.31	7.6	15	48	32	6	3.1	6.5	9.5	12.6	25	54	21

a. Total of internal and external trips generated by area residents.
b. Source: 1970 Census.
c. Source: Origin-Destination Surveys.
d. Calculated (using b).
e. Calculated (using b and c).
f. Source: References (17 and 19).

Source: NCHRP Report #187, Quick Response Urban Travel Estimation Techniques and Transferable Parameters.

	Auto Ownership Level			
	0	1	2	3+
Average Daily Person-Trips per Household	3.4	7.5	10.1	13.6

The distribution of households by auto ownership was previously determined to be:

	Auto Ownership Level			
	0	1	2	3+
Percentage of Total Households	11.5	59.0	28.0	1.5

Applying this distribution to the average person-trip rates shown above yields:

$$.115 \text{ X } 3.4 + .590 \text{ X } 7.5 + .280 \text{ X } 10.1 + .015 \text{ X } 13.6 = 7.85 \ \frac{\text{person trips}}{\text{day}}$$

Both home-based non-work (HBNW) and non-home-based (NHB) trips were included in the non-work trip category for this analysis. Table I-1 further indicates that 53 percent of the total person trips are home-based non-work and 21 percent are non-home based. Table I-2 (Table 3 from NCHRP 187) indicates that for large urban areas, the number of auto driver trips is approximately 53 percent of homebased non-work trips and 60 percent of non-home based trips. The average daily number of non-work auto trips per household in the corridor can be approximated as:

$$\begin{aligned} &7.85 \ \frac{\text{Total Trips}}{\text{Day}} \times .53 \ \frac{\text{HBNW Trips}}{\text{Total Trips}} \times .53 \ \frac{\text{Auto Trips}}{\text{HBNW Trips}} + 7.85 \ \frac{\text{Total Trips}}{\text{Day}} \\ &.21 \ \frac{\text{NHB Trips}}{\text{Total Trips}} \times .60 \ \frac{\text{Auto Trips}}{\text{NHB Trips}} = 3.19 \ \frac{\text{Auto Trips}}{\text{Day}} \end{aligned}$$

TABLE I-2

TRIP-GENERATION PARAMETERS

PART A - TRIP PRODUCTION ESTIMATES

Urbanized Area Population	Average Daily Person Trips Per HH[a]	% Average Daily Person Trips by Mode[b]			% Average Daily Person Trips by Purpose[a]			Auto Person Trips as a % of Total Person Trips[c]			Auto Driver Trips as a % of Total Person Trips[d]		
		Public Transit	Auto Passenger	Auto Driver	HBW	HBNW	NHB	HBW	HBNW	NHB	HBW	HBNW	NHB
50,000- 100,000	14	2	40	58	16	61	23	96	99	98	70	54	68
100,000- 250,000	14	6	30	64	20	57	23	88	97	94	64	54	66
250,000- 750,000	12	8	31	61	20	55	25	84	96	92	62	54	64
750,000-2,000,000	8	13	30	57	25	54	21	74	93	86	56	53	60

PART B - USEFUL CHARACTERISTICS FOR TRIP ESTIMATION

Urbanized Area Population	External Travel Characteristics		Total Areawide Truck Trips as a % of Areawide Auto Driver Trips[f]
	% of Total External Trips Passing Through Area[e]	% of Total External Trips to the CBD[e]	
50,000- 100,000	21	22	27
100,000- 250,000	15	22	17
250,000- 750,000	10	18	16
750,000-2,000,000	4	12	16

PART C - TRIP ATTRACTION ESTIMATING RELATIONSHIPS[g]
(All Population Groupings for either Vehicle or Person Trips)

TO ESTIMATE TRIP ATTRACTIONS FOR AN ANALYSIS AREA, USE:

$$\text{HBW Trip Attractions} = F_1 \left[1.7 \text{ (Analysis Area Total Employment)} \right]$$

$$\text{HBNW Trip Attractions} = F_2 \left[10.0 \begin{pmatrix} \text{Analysis Area} \\ \text{Retail} \\ \text{Employment} \end{pmatrix} + 0.5 \begin{pmatrix} \text{Analysis Area} \\ \text{Non-Retail} \\ \text{Employment} \end{pmatrix} + 1.0 \begin{pmatrix} \text{Analysis Area} \\ \text{Dwelling} \\ \text{Units} \end{pmatrix} \right]$$

$$\text{NHB Trip Attractions} = F_3 \left[2.0 \begin{pmatrix} \text{Analysis Area} \\ \text{Retail} \\ \text{Employment} \end{pmatrix} + 2.5 \begin{pmatrix} \text{Analysis Area} \\ \text{Non-Retail} \\ \text{Employment} \end{pmatrix} + 0.5 \begin{pmatrix} \text{Analysis Area} \\ \text{Dwelling} \\ \text{Units} \end{pmatrix} \right]$$

Where: F_1, F_2 and F_3 are areawide control factors.

TO DEVELOP AREAWIDE CONTROL FACTORS, USE:

$$F_1 = \frac{\text{Areawide Productions for HBW Trips}}{1.7 \text{ (Areawide Total Employment)}}$$

$$F_2 = \frac{\text{Areawide Productions for HBNW Trips}}{\left[10.0 \begin{pmatrix} \text{Areawide} \\ \text{Retail} \\ \text{Employment} \end{pmatrix} + 0.5 \begin{pmatrix} \text{Areawide} \\ \text{Non-Retail} \\ \text{Employment} \end{pmatrix} + 1.0 \begin{pmatrix} \text{Areawide} \\ \text{Dwelling} \\ \text{Units} \end{pmatrix} \right]}$$

$$F_3 = \frac{\text{Areawide Productions for NHB Trips}}{\left[2.0 \begin{pmatrix} \text{Areawide} \\ \text{Retail} \\ \text{Employment} \end{pmatrix} + 2.5 \begin{pmatrix} \text{Areawide} \\ \text{Non-Retail} \\ \text{Employment} \end{pmatrix} + 0.5 \begin{pmatrix} \text{Areawide} \\ \text{Dwelling} \\ \text{Units} \end{pmatrix} \right]}$$

---

a. From Table 2.
b. Source: Ref. (19).
c. Source: Origin-Destination Surveys.
d. Calculated using c and Table 12, Chapter Five.
e. Source: Ref. (20).
f. Source: Ref. (19).
g. Source: Office of Planning Methodology and Technical Support, UMTA.

Source: NCHRP Report #187, Quick Response Urban Travel Estimation Techniques and Transferable Parameters.

All of these trips must be made by households owning autos. Since 11.5 percent of the corridor's households own no autos, the average daily frequency of non-work auto trips for auto-owning households must be:

$$3.19 \div .885 = 3.61 \; \frac{\text{trips}}{\text{day}} \quad \div \; 2 \; \frac{\text{trips}}{\text{round trip}} = 1.80 \; \frac{\text{round trips}}{\text{day}}$$

This figure is entered on column 4 of Worksheet I for the auto owning subgroups, while "0" is entered for the two subgroups without autos.

Base Work Trip Modal Shares

Screenline counts on the freeway and major arterials leading from the corridor into the central city and alighting counts on transit routes serving the city from the corridor were conducted to determine:

- The total volume of auto person trips from the corridor to the central city;
- The volume of transit riders in the corridor; and
- The distribution of auto occupancy for central city work trips

The information from these counts may be used to determine the base mode shares required for the manual worksheet analysis.

Counts were conducted on a typical workday and yielded the following results:

Total Auto Person Trips - 48,910
One Person - 23,230
Two Person - 16,042
Three Person - 5,016
Four+ Person - 4,622
Average Size of Four+ Carpool - 4.60

Total Auto Person Trips to Fringe Area	-	19,564 (40% of Total)
Total Auto Person Trips to CBD	-	29,346 (60% of Total)
Total Transit Passengers to Fringe	-	5,707 (40% of Total)
Total Transit Passengers to CBD	-	8,560 (60% of Total)

License plate numbers were recorded for a sample of the autos passing the screenline and vehicle registrations were checked to determine the residence location of the driver. It was found that 45 percent of the vehicles passing the screenline had origins outside the corridor, or in locations within the corridor which would be unaffected by the HOV lanes or improved bus service (areas A on the map of the corridor shown in Figure I-4). Similar checks were made for bus passengers using boarding counts on a sample of the routes, yielding an estimate of 10 percent of downtown bound passengers on corridor routes who would be unaffected by the proposed measures.

The person trip counts and the percentages of unaffected trips yielded the following estimates of travel volumes and mode shares for central city bound trips in the corridor which could potentially be affected by the HOV lane proposal:

	Auto Trips (Occupancy)				Transit Trips	Total Trips
	1	2	3	4+		
Total	12,776	8,823	2,759	2,542	12,840	39,740
Share (%)	32.2	22.3	6.9	6.4	32.2	100.0

Worksheet I provides space for recording base mode shares of drive-alone, carpool, transit, and other modes only. Because two- and three-person carpools will be affected differently from four-person-and-larger carpools, the base shares for both of these size categories must be

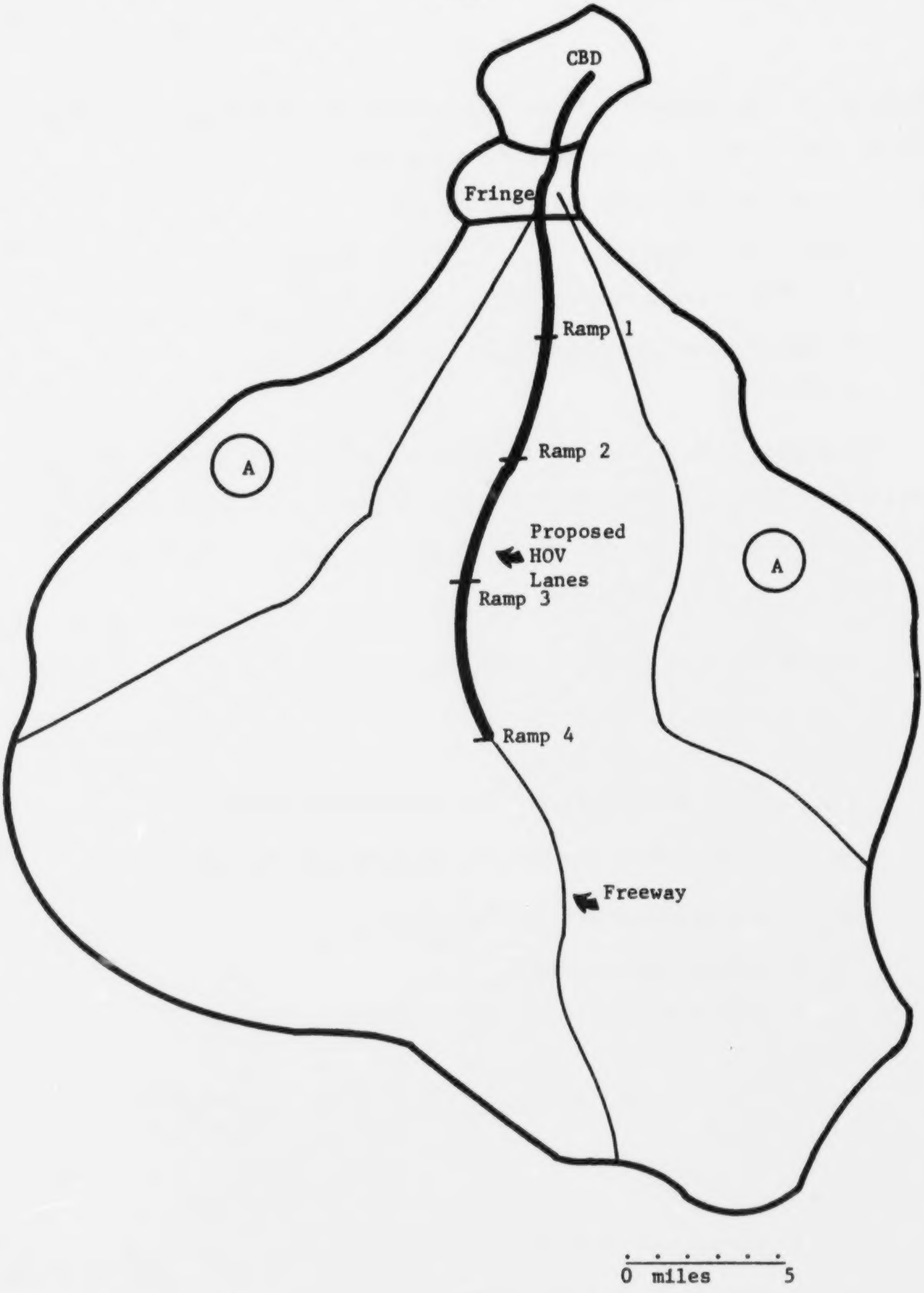

FIGURE I-4

Study Corridor and Proposed HOV Lanes

recorded for this analysis. It was assumed that the mode shares for CBD and fringe area workers were approximately the same. The average mode shares for all households in the corridor are:

Drive Alone (DA):	32.2%
Two-, Three-person Carpools (SR_{23}):	29.2%
Four-plus person Carpools (SR_{4+}):	6.4%
Transit	32.2%

Adjustments must be made to these average mode shares when recording the base work trip mode shares for each market segment since the subgroup not owning autos can not use the drive-alone mode. These adjustments were accomplished as follows:

$$DA_o = 0 \; ; \; T_o = \frac{T_a}{SR_a + T_a} \; ; \text{ and } SR_o = \frac{SR_a}{SR_a + T_a}$$

Where:

DA_o = Drive Alone share for zero auto-owning households

T_o = Transit Share for the Zero Auto-Owning Subgroup

SR_a = Shared-Ride Share (all carpools)

T_a = Average Transit Share

SR_o = Shared-Ride Share for Zero Auto-Owning Subgroup

$$DA_1 = \frac{DA_a}{F_1} \qquad SR_1 = \frac{SR_a - SR_o F_o}{F_1} \qquad T_1 = \frac{T_a - T_o F_o}{F_1}$$

Where:

DA_1 = Drive-Alone Share for Auto-Owning Subgroup

DA_a = Average Drive-Alone Share

SR_1 = Shared-Ride Share for Auto-Owning Subgroup

T_1 = Transit Share for Auto-Owning Subgroup

Fo = Fraction of Households Owning Zero Autos

F_1 = Fraction of Households Owning One or More Autos

Applying these formulas to the average mode shares for the corridor, and assuming that the breakdown of carpools by size (82.0 percent of carpools are two or three persons) is not dependent on auto ownership yielded the following mode shares for each market segment:

Subgroups 2 and 4:

$$DA_0 = 0$$

$$SR_0 = \frac{.356}{.322 + .356} = .525$$

$$T_0 = \frac{.322}{.322 + .356} = .475$$

$$SR_{23} = .525(.820) = .431$$

$$SR_{4+} = .525(.18) = .094$$

Subgroups 1 and 3:

$$DA_1 = \frac{.322}{.885} = .364$$

$$SR_1 = \frac{.356 - .525(.115)}{.885} = .334$$

$$T_1 = \frac{.322 - .475(.115)}{.885} = .302$$

$$SR_{23} = .334(.82) = .274$$

$$SR_{4+} = .334(.18) = .060$$

The mode shares for each subgroup are entered on colums 5 through 8 on Worksheet I. Note that the share for other modes is zero in this case. Also note that if the average mode shares had been different for the fringe and CBD areas, the above calculations would have been carried out separately for each subgroup.

Average Carpool Size

The average carpool size, required in column 9, may be calculated from the distribution of auto occupancies available in the screenline count data. Once again, distinction must be made between two- and three-person, and larger carpools. The average size for two- and three-person carpools is:

$$2\left(\frac{.223}{.223 + .069}\right) + 3\left(\frac{.069}{.223 + .069}\right) = 2.2$$

The average occupancy of larger carpools was found to be 4.6 according to the screenline counts.

Average Trip Length

The final pieces of base data required for the analysis are work and non-work trip lengths. In this analysis, average work trip length was determined using approximate measurements on a map of the area and a knowledge of the distribution of traffic entering the freeway along its length. Figure I-4 shows the planned entrance ramps for the freeway HOV lanes. The percentage of the total freeway traffic currently entering at each point is known to be:

Ramp 1 (8.5 miles from the CBD)	- 40%
Ramp 2 (11.5 miles)	- 20%
Ramp 3 (15.0 miles)	- 20%
Ramp 4 and beyond (16.5 miles)	- 20%

The fringe area and the CBD are about 5 miles apart, so the freeway portion of average trip lengths in the corridor is 7 miles for fringe area work trips and 12 miles for CBD work trips. The population distribution in the corridor and the location of major arterials paralleling the freeway indicate that the average freeway and arterial access distance is about 2 miles, and central city circulation accounts for about 0.5 miles on the average. The total trip lengths of 14.5 and 9.5 miles for CBD and fringe trips are recorded in column 10 of Worksheet I. Non-work trip length data was not available for the area, so a 3-mile trip length was assumed for auto-owning households based on national average trip length figures. Non-work trip lengths for households without autos are not needed since it is assumed that these households make no auto trips.

Average Daily VMT

The information required in the final three columns of Worksheet I will be calculated using Worksheet I-A. Worksheet I-A is executed for each of the four population subgroups using data from Worksheet I. The entries for subgroup 1 are shown as an example. As in the case of the base data, separate consideration of two- and three-person and four-plus person carpools is necessary. Base autos used per worker for subgroup 1 is calculated:

$$.274 \text{ (2,3 carpool share)} \div 2.2 \left(\frac{\text{persons}}{\text{2,3 carpool}}\right) + .060 \text{ (4+ carpool share)} \div 4.6 \left(\frac{\text{Persons}}{\text{4+ Carpool}}\right) + .364 \text{ (Drive-alone share)} = .502 \ \frac{\text{autos}}{\text{worker}}$$

Similar calculations are made for the other three subgroups.

Changes in Transportation Level of Service (LOS)

Worksheet II-A is used with the slight modifications shown to record LOS changes for carpools of differing size. The base carpool size shares

I. BASE DATA

POLICY: HOV Lane

Population Subgroup*	Fraction of Total Population	Average Household Data			Base Work Trip Modal Shares				Average Carpool Size ***	Average Trip Length		Average Daily VMT		
		Annual Income $	Number of Workers	Number of Non-Work Auto Trips	Drive Alone	Shared Ride **	Transit	Other		Work (one way)	N[illegible] (one way)	Work	Non-Work	Total
1	.531	13,440	1.2	1.8	.364	.274 .060	.302	0	2.2 4.6	14.5	3			
2	.069	13,440	1.2	0	0	.431 .094	.475	0	2.2 4.6	14.5	-			
3	.354	13,440	1.2	1.8	.364	.274 .060	.302	0	2.2 4.6	9.5	3			
4	.046	13,400	1.2	0	0	.431 .094	.475	0	2.2 4.6	9.5	-			

*1 CBD Destination All Modes Available
2 CBD Destination DA Not Available
3 Fringe Destination All Modes Available
4 Fringe Destination DA Not Available

**Two shared-ride mode shares must be recorded for each subgroup:

***Two average carpool sizes, 2 and 3 person, and 4+ person are required also: X/Y

X = 2 and 3 person carpools

Y = 4+ person carpools

I-A. BASE VMT

POLICY: HOV Lane
SUBGROUP: 1

1. BASE HOUSEHOLD WORK TRIP VMT

Base Shared Ride Modal Share		Base Average Carpool Size		Base Drive Alone Modal Share		Base Autos Used per Worker
.274 .060	÷	2.2 4.6	+	.364	=	.502

Base Autos Used per Workers		No. of Workers per Household		Work Trip Length				Base Household Work VMT
.502	X	1.2	X	14.5	X	2.0	=	17.47

2. BASE HOUSEHOLD NON-WORK TRIP VMT

No. of Non-Work Auto Trips		Non-Work Trip Length				Base Household Non-Work VMT
1.8	X	3	X	2.0	=	10.8

3. BASE HOUSEHOLD TOTAL VMT

Base Household Work VMT		Base Household Non-Work VMT		Base Household Total VMT
17.47	+	10.8	=	28.27

and average size of four-plus person carpools required by Worksheet II-A have already been determined. The LOS changes must be estimated separately for each population subgroup and carpool size and recorded on Worksheet II-A.

1. CBD Workers (Groups 1 and 2)

Two- and Three-person Carpools - All autos will experience delays due to construction in the downtown area. The average diversion of autos due to the construction is expected to be about .5 mile. Current travel speeds downtown are 17 mph, so the diversion translates into 1.76 minutes in each direction or 3.5 minutes of additional travel time for the round trip. This is the only impact expected for two- and three-person carpools since they cannot use the HOV lane.

Four-plus person carpools - These autos will experience the 3.5-minute delay downtown, but will also save time because they can use the HOV lane. As noted earlier, the average length of the freeway section of downtown-bound trips is 12 miles, or 24 miles round trip. Because of congestion during the peak hour, the average speed on the freeway is now 22 mph. The average speed for the HOV lanes is expected to be about 50 mph. The average time saved on the freeway for four-plus person carpools will thus be:

$$\frac{24\text{ miles}}{22\text{ mph}} \times \frac{60\text{ min.}}{\text{hr.}} - \frac{24\text{ miles}}{50\text{ mph}} \times \frac{60\text{ min}}{\text{hr}} = 36.7\text{ minutes}$$

To obtain these time savings, some of the carpoolers will have to go out of their way to get to the freeway (rather than using one of the major arterials in the corridor which would provide a more direct route to the central city). Standard diversion curves may be used to determine the degree to which the HOV lanes will cause carpoolers to divert from their current routes on the major arterials.[1] Curves developed by Moskowitz,[2] based on time savings via a freeway versus arterials, and the extra distance required to use the freeway, are particularly useful for this analysis (See Figure I-5). In order to apply the curves, a knowledge of the distribution of the population by distance from the freeway is necessary. Land use maps of the corridor indicate that in 1982, the following distribution will exist:

Distance from Freeway	Percent of Corridor Population
0-1 miles	30.0%
1-2 miles	26.3%
2-5 miles	30.2%
5+ miles	13.5%

Currently, 26 percent of the corridor traffic to the central city uses the freeway. Given the current freeway speed of 22 mph and arterial speeds averaging 20 mph, it is assumed that all of the travellers currently using the freeway must live within one mile of the freeway, since there are no time savings associated with diversions to the freeway from greater distances. However, with the institution of reserved lanes for buses and carpools, diversion can be expected to occur to a much greater degree.

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[1] For a compilation of typical diversion curves, see Martin, B.V., F.W. Memmott, and A.J. Bone, Principals and Techniques of Predicting Future Demand for Urban Area Transportation, January, 1963.

[2] K. Moskowitz, "California Method of Assigning Diverted Traffic to Proposed Freeways," Highway Research Bulletin 130, 1956.

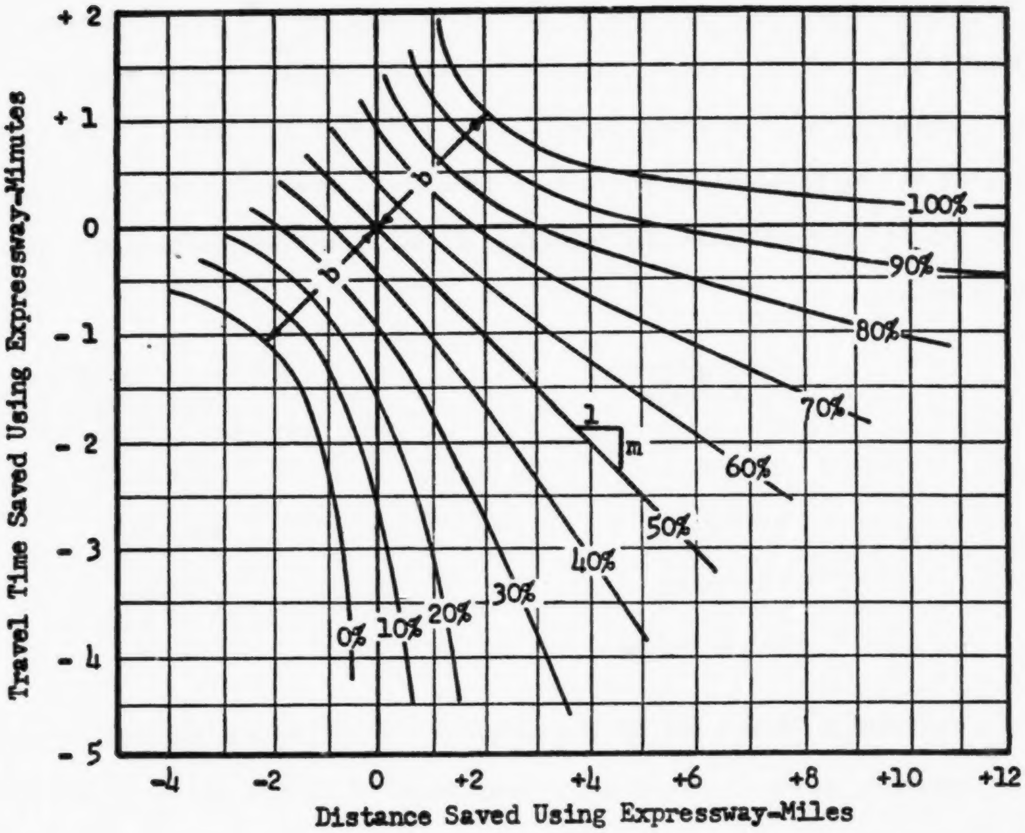

FIGURE I-5

Freeway/Arterial Diversion Curves

Source: Moskowitz, HRB Bulletin 130

The net one-way time savings for each of the above distance categories may be calculated:

$$S_N = \frac{36.7 \text{ minutes}}{2} - \frac{d}{20 \text{ mph}} \times 60$$

where: d = the average distance from the freeway

These time savings may then be used in combination with the extra distance associated with freeway travel to enter the route diversion curves and determine the proportion of the population in each distance category which will use the freeway. The net travel time savings, extra distance travelled and percent of the four-plus person carpools within each distance category diverting to the freeway are shown below:

Distance Category	Net Travel Time Savings	Extra Distance Travelled	Percent of 4+ Person Carpools Using Freeway HOV Lanes
0-1	16.9 min.	0.5 mile	100%
1-2	13.9 min.	1.5 miles	80%
2-5	2.9 min.	3.5 miles	53%
5+	0 min.	6.5 miles	0%

The average round-trip travel time savings for all carpools in the corridor may be calculated from the percent diversion for each distance category, the percent of the population in each category, and the round-trip net time savings, recalling that 26 percent of the population (all within one mile of the HOV lanes) would not divert from their current route at all:

$$.26(36.7) + 1.0(.30 - .26)(16.9)(2) +$$

$$.80(.263)(13.9)(2) + .53(.302)(7.9)(2) = 19.2 \text{ minutes}$$

These carpoolers will be delayed, along with all other auto traffic in the downtown area, by 3.5 minutes. Therefore, the net time savings will be 15.7 minutes overall for four-plus person carpools bound to the CBD. This is entered under ΔIVTT for four-plus person carpools on Worksheet II-A for sub-groups 1 and 2.

2. Fringe Area Workers (groups 3 and 4)

Two- and Three-person Carpools - Approximately half of the employees in the fringe area will be affected by the employer carpool parking policy. Among these employees, single-occupant auto drivers will have longer walks, on the average, from their parking spaces to their offices, while carpoolers will have shorter walks. The current average walk distance for all employees is approximately 700 feet. Under the preferential policy, the average walk distance for all carpoolers will be 350 feet. Walking speed averages 264 feet per minute (3 mph), so the one-way walk time savings for carpoolers averages 1.33 minutes. This savings is doubled for the round trip, but only half the fringe area employees would be affected, so the average impact for all employees is a 1.33 minute round trip savings. This is recorded on Worksheet II-A in column 5—ΔOVTT. No other changes in LOS are expected for two- and three-person carpoolers.

Four-plus Person Carpools - These travellers will enjoy the 1.33-minute OVTT savings from preferential parking, plus travel time savings on the HOV lanes of the freeway. The freeway travel time savings, based on a

II-A. CHANGES IN TRANSPORTATION LEVEL OF SERVICE BY CARPOOL SIZE

POLICY: HOV Lane

Population Subgroup	Base Carpool-Size Shares		Average Size of 4+ Person Carpools	Changes in Transportation Level of Service (Round Trip)							
				2,3 Person Carpool				4 + Person Carpool			
	2,3 Person	4+Person		In-Vehicle Travel Time $\Delta IVTT_2$ min.	Out-of-Vehicle Travel Time $\Delta OVTT_2$ min.	Out-of-Pocket Travel Cost $\Delta OPTC_2$ ¢	Promotion and Matching Incentives 0,1	In-Vehicle Travel Time $\Delta IVTT_{3+}$	Out-of-Vehicle Travel Time $\Delta OVTT_{3+}$	Out-of-Pocket Travel Cost $\Delta OPTC_{3+}$	Promotion and Matching Incentives 0,1
1	.882	.118	4.6	+3.5	0	0	0	-15.7	0	0	0
2	.882	.118	4.6	+3.5	0	0	0	-15.7	0	0	0
3	.882	.118	4.6	0	-1.33	0	0	-9.36	-1.33	0	0
4	.882	.118	4.6	0	-1.33	0	0	-9.36	-1.33	0	0

7-mile average distance is estimated to be 22.9 minutes for fringe area four-plus person carpoolers. Using the same distance categories, diversion curves, and calculations as in the CBD-bound case, the following results are obtained:

Distance Category	Net Travel Time Savings	Extra Distance Travelled	Percent of 4+ Person Carpools Using Freeway HOV Lanes
0-1	10 min.	0.5 mile	90%
1-2	7 min.	1.5 miles	70%
2-5	1 min.	3.5 miles	18%
5+	3.5 min.	5.0 miles	0%

Average Round trip savings:

$$.26(22.9) + .90(.30 - .26)(20) +$$
$$.70(.263)(14) + .18(.302)(2) \quad = \quad 9.36 \text{ minutes}$$

This savings figure is entered under ΔIVTT for four-plus person carpools for subgroups 3 and 4.

As illustrated in Figure I-2, changes in carpool size as a result of the differential impact of the transportation measures on two-, three-, and four-plus person carpools must now be determined. The new proportions of carpools by size will then be used to calculate the average level-of-service impact on the carpool mode as a whole. Worksheet III-A is used to estimate the changes in the distribution of carpool sizes. The analysis of this particular carpool/bus lane proposal requires a non-standard use of Worksheet III-A, since only carpools with four or more members are eligible to use the reserved-lane facility. The only change required is to include two- and three-person carpools in the calculations of change in utility for carpools with two members, and only carpools of four or more members in the three-plus person carpool calculations. The average two- and three-person carpool size of 2.2 is substituted for the two-person carpool size, and the average four-plus carpool size of 4.6 is used for the average three-plus carpool size in the calculation of overall average carpool size.

Worksheet III-A is used once for each of the population subgroups. The calculations for subgroups 1 and 2 are provided as an example (the calculations for groups 1 and 2, and groups 3 and 4 are identical). All of the data required for Worksheet III-A has been recorded on previous worksheets.

The revised changes in shared-ride LOS calculated in Section 3 of Worksheet III-A represent the average changes in service quality for the ridesharing mode, given the changes in carpool size which are likely to occur because of the difference in impact of the planned transportation measures on four-plus person carpools relative to smaller carpools. These average shared-ride LOS changes are now entered on Worksheet II; along with the LOS changes for the other modes described in the following sections.

Drive Alone

The only impact on drive-alone trips to the CBD will be the 3.5-minute delay for downtown circulation due to construction. This will affect subgroup 1 only, since subgroup 2 does not have the drive-alone option available.

POLICY: HOV Lane
SUBGROUP: 1/2

III-A. ESTIMATION OF CHANGES IN CARPOOL SIZE

1. CHANGE IN UTILITY FOR EACH CARPOOL SIZE

2,3 Person Carpool

ΔUTILITY = -.015 × $\Delta IVTT_2$ 3.5 = -.053
+ -.16 ÷ Trip Length 14.5 × $\Delta OVTT_2$ 0 = 0
+ -29.0 ÷ Income 13,440 × $\Delta OPTC_2$ 0 ÷ 2,3 Person Carpool Size 2.2 = 0
+ .29 × Incentives 0 = 0

TOTAL CHANGE -.053

4 + Person Carpool

ΔUTILITY = -.015 × $\Delta IVTT_3$ -15.7 = +.236
+ -.16 ÷ Trip Length 14.5 × $\Delta OVTT_3$ 0 = 0
+ -29.0 ÷ Income 13,440 × $\Delta OPTC_3$ 0 ÷ Average 4+ Carpool Size 4.6 = 0
+ .29 × Incentives 0 = 0

TOTAL CHANGE +.236

2. REVISED CARPOOL-SIZE SHARES

	Base Share		ΔUtility				Total Share		Revised Share
2,3 Person	.820	X EXP	-.053	=	.778	÷	1.006	=	.773
4+ Person	.180	X EXP	-.236	=	.228	÷	1.006	=	.227

Total Share = 1.006

3. REVISED CHANGES IN SHARED RIDE LEVEL-OF-SERVICE (LOS)

	Revised 2,3 Person Share		2,3 Person ΔLOS		Revised 4+ Person Share		4+ Person ΔLOS		Shared Ride ΔLOS
ΔIVTT	.773	X	3.5	+	.227	X	-15.7	=	-.858
ΔOVTT	.773	X	0	+	.227	X	0	=	0
ΔOPTC	.773	X	0	+	.227	X	0	=	0
Incentives	--	X	--	+	--	X	--	=	0

4. REVISED AVERAGE CARPOOL SIZE

1.0 ÷ ((Revised 2 Person Share .773 ÷ 2,3 Person Carpool Size 2.2) + (Revised 4+ Person Share .227 ÷ Average 4+ Carpool Size 4.6)) = Revised Average Carpool Size 2.50

Half of the drive-alone commuters bound to the fringe area will be affected by the preferential carpool parking policy planned by some employers. The average walking distance for those who do not carpool is expected to increase to 1,500 feet from the current average of 700 feet. At 264 feet per minute (3 mph), the 800-foot increase in walking distance will delay drive-alone commuters 3.0 minutes. Half the employees will experience the delay twice daily, so the round-trip average change in OVTT is +3.0 minutes. Again, this will only impact auto-owning households (subgroup 3). These LOS changes are entered on Worksheet II under Drive-Alone.

Transit

Two important changes in transit level of service are associated with the proposed plan. Travel times will be reduced on those routes which use the HOV lanes, and wait times will be lowered due to higher frequency service.

It is assumed that the distribution of bus passengers entering the freeway high-occupancy vehicle lanes will be similar to that for carpools and autos, and that the average one-way distance for buses going to the CBD will be 12 miles on the HOV lanes, and the average to the fringe area 7 miles. It is also assumed that buses will travel 50 mph on the lanes, compared to 22 mph under current conditions. According to the plans of the bus operator, approximately 60 percent of the buses serving the corridor will use the HOV lanes. Therefore, the average time savings for central city-bound bus passengers in the corridor will be:

$$\text{CBD-Bound:}\left(\frac{12\text{ miles}}{22\text{ mph}} - \frac{12\text{ miles}}{50\text{ mph}}\right) \times 60\ \frac{\text{minutes}}{\text{hours}}$$

$$\times\ 0.6\ (\text{fraction using HOV lanes}) \times 2\left(\frac{\text{one-way trips}}{\text{round trip}}\right)$$

$$= 22.0\text{ minutes}$$

Similarly,

$$\text{Fringe area-Bound:}\ \left(\frac{7\text{ miles}}{22\text{ mph}} - \frac{7\text{ miles}}{50\text{ mph}}\right) \times 60\text{ minutes per hour}$$

$$\times\ 0.6\ (\text{fraction using HOV lanes}) \times 2\left(\frac{\text{one-way trips}}{\text{round trip}}\right)$$

$$= 12.8\text{ minutes}$$

These average savings in bus IVTT will be enjoyed by all residents in the corridor, regardless of auto ownership.

The bus fleet serving the corridor will be doubled to take advantage of the HOV lanes and encourage their use by commuters in express buses. On the average, it is estimated that headways will be cut in half, although headways on some routes will be improved more than on others. The average headway for radial routes in the corridor is now 20 minutes, and should be reduced to 10 minutes when the new services are in place. Assuming waiting times are approximately half the headway, a 5-minute average reduction in waiting times (OVTT) for all central city-bound bus passengers will occur. No changes in bus fares are planned.

The average drive-alone, shared-ride, and transit changes in level of service should now be entered on Worksheet II. This completes the preparation of input data for the analysis, and the analyst is ready to begin Step 5 using Worksheet III.

II. CHANGES IN TRANSPORTATION LEVEL OF SERVICE (ROUND TRIP)

POLICY: HOV Lane

Population Subgroup	Drive Alone			Shared Ride				Transit		
	In-Vehicle Travel Time $\Delta IVTT_{da}$ min.	Out-of-Vehicle Travel Time $\Delta OVTT_{da}$ min.	Out-of-Pocket Travel Cost $\Delta OPTC_{da}$ ¢	In-Vehicle Travel Time $\Delta IVTT_{sr}$ min.	Out-of-Vehicle Travel Time $\Delta OPTC_{sr}$ min.	Out-of-Pocket Travel Cost $\Delta OPTC_{sr}$ ¢	Carpool Promotion & Matching Incentives 0,1	In-Vehicle Travel Time $\Delta IVTT_{t}$ min.	Out-of-Vehicle Travel Time $\Delta OVTT_{t}$ min.	Out-of-Pocket Travel Cost $\Delta OPTC_{t}$ ¢
1	+3.5	0	0	-.86	0	0	0	-22.0	-5.0	0
2	-	-	-	-.86	0	0	0	-22.0	-5.0	0
3	0	+3.0	0	-1.89	-1.33	0	0	-12.8	-5.0	0
4	-	-	-	-1.89	-1.33	0	0	-12.8	-5.0	0

G. Description of Model Application

Steps 5 and 6 of the analysis are accomplished using Worksheets III, IV, V, and V-A. Worksheet III is executed four times, once for each of the four population subgroups being analyzed to determine new mode shares as a consequence of the changes in LOS. The worksheet for subgroup 1 provides an example of the flow of data from previous worksheets and the calculations required for each subgroup.

The change in level of service required for each mode is taken from Worksheet II for each market segment. In this case, drive-alone ΔIVTT is 3.5, shared-ride ΔIVTT is -.86, transit ΔIVTT is -22.0, and transit ΔOVTT is -5.0. All other level-of-service changes are zero. The required trip length and income statistics for subgroup 1 are obtained from Worksheet I, along with the base mode shares required in Part 2 of the Worksheet. The shared-ride share used in Worksheet III is the combined two-, three-, and four-plus person share (33.4 percent for sub-group 1.). The Δ utility inputs in Part 2 of Worksheet III are the "total changes" calculated for each mode in Part 1 of the same worksheet. The mode shares calculated in Part 2 reflect the predicted travel response of the particular subgroup to the proposed plans. Thus it is possible through the use of the manual worksheets to isolate the impacts of proposed transportation measures on particular population groups.

The new mode shares calculated using Worksheet III are then used, along with data from Worksheet 1-A (base work and non-work VMT, trip lengths, and workers per household) and Worksheet III-A (revised average

III. ESTIMATION OF REVISED WORK-TRIP MODAL SHARES

POLICY: HOV Lane
SUBGROUP: 1

1. CHANGE IN UTILITY FOR EACH MODE

Drive Alone

ΔUTILITY = -.015 × +3.5 ($\Delta IVTT_{da}$) = -0.053
+ -.16 ÷ 14.5 (Trip Length) × 0 ($\Delta OVTT_{da}$) = 0
+ -29.0 ÷ 13,440 (Income) × 0 ($\Delta OPTC_{da}$) = 0

TOTAL CHANGE -0.053

Shared Ride

ΔUTILITY = -.015 × -.86 ($\Delta IVTT_{sr}$) = +0.013
+ -.16 ÷ 14.5 (Trip Length) × 0 ($\Delta OVTT_{sr}$) = 0
+ -29.0 ÷ 13,440 (Income) × 0 ($\Delta OPTC_{sr}$) ÷ 2.5 (Average Car-pool Size) = 0
+ .29 × -- (Incentives) = 0

TOTAL CHANGE +0.013

Transit

ΔUTILITY = -.015 × -22.0 ($IVTT_t$) = +0.330
+ -.16 ÷ 14.5 (Trip Length) × -5.0 ($OVTT_t$) = +0.055
+ -29.0 ÷ 13,440 (Income) × 0 ($OPTC_t$) = 0

TOTAL CHANGE +0.385

2. REVISED MODAL SHARE

	Base Modal Share		ΔUtility			Total	Revised Share
Drive Alone	= .364	× EXP	-.053	= .345	÷	1.127	= .306
Shared Ride	= .334	× EXP	+.013	= .338	÷	1.127	= .300
Transit	= .302	× EXP	+.385	= .444	÷	1.127	= .394
Vanpool	= 0	× EXP	--	= --	÷	--	= --
Other	= 0	×	1.0	= --	÷	--	= --
			Total	= 1.127			

carpool size) in executing Worksheet IV for each population subgroup. The revised work and non-work VMT calculated for each subgroup on Worksheet IV is then summarized and translated into average corridor-wide changes in work and non-work VMT on Worksheet V. Worksheet V-A is used to summarize the predicted mode share impacts and calculate corridor-wide average mode shares under the new conditions. An example of the use of Worksheet IV is provided for subgroup 1, and the attached Worksheets V and V-A show the predicted impacts of the proposed HOV lane plans for all population subgroups in the corridor.

In order to isolate the impacts of the proposed plans on four-plus person carpools, the revised two- and three-person, and four-plus person carpool shares calculated in Worksheet III-A for each market segment must be applied to the revised overall carpool share calculated on Worksheet III. This is done on the sample Worksheet V-A. Note that the vanpool sections of Worksheets III, IV, V, and V-A are ignored for this analysis. Also, the non-work VMT section of Worksheet IV can be ignored for subgroups 2 and 4 since these subgroups do not make non-work auto trips.

H. Impact Assessment

To determine the impacts of the mode shifts and percentage changes in VMT summarized on Worksheets V and V-A on HC and NOx emissions in the corrider (Step 7 of the analysis), total VMT changes must be calculated. The distribution of auto person trips by auto occupancy level (pg. 11) yields:

$$\frac{12,776}{1} + \frac{8823}{2} + \frac{2759}{3} + \frac{2542}{4} = 18,743 \text{ auto trips}$$

We know that 40 percent of the work trips average 9.5 miles one way and 60 percent average 14.5 miles one way. The total base work VMT is then:

IV. ESTIMATION OF CHANGES IN VMT

POLICY HOV Lane
SUBGROUP 1

1. REVISED HOUSEHOLD WORK TRIP VMT

Revised Shared Ride Modal Share		Revised Average Carpool Size		Revised Drive Alone Modal Share		Revised Autos Used Per Worker
.300	÷	2.5	+	.306	=	.426

Revised Autos Used per Worker		No. of Workers per Household		Work Trip Length				Auto VMT
.426	x	1.2	x	14.5	x	2.0	=	14.82

Revised Vanpool Modal Share		Average Vanpool Occupancy		No. of Workers per Household		Work Trip Length		Vanpool Circuity Factor				Vanpool VMT
--	÷	--	x	--	x	--	x	--	x	2.0	=	--

Total Revised Household Work VMT 14.82

2. CHANGE IN HOUSEHOLD WORK TRIP VMT

Revised Household Work-Trip VMT		Base Work Trip VMT		Change in Work Trip VMT		Base Work Trip VMT				% Change in Work Trip VMT
14.82	−	17.47	=	-2.65	÷	17.47	x	100	=	-15.17

3. REVISED HOUSEHOLD NON-WORK TRIP VMT

	Base Autos Used per Worker		Revised Autos Used per Worker			No. of Workers per Household		Change in Autos Remaining per Household
{	.502	−	.426	}	x	1.2	=	+.0912

	Change in Autos Remaining per Household							Base Non-Work VMT		Revised Non-Work VMT
{	+.0912	x	.08	+	1.0	}	x	10.80	=	10.88

4. CHANGE IN TOTAL HOUSEHOLD VMT FROM BASE

Revised Work Trip VMT		Revised Non-Work VMT		Revised Total VMT
14.82	+	10.88	=	25.70

Base Total VMT
− 28.27

							% Change in Total VMT
Change in Total VMT	-2.57	÷	28.27	x	100	=	-9.09

V. SUMMARY OF CHANGES IN VMT

POLICY: HOV Lane

Population Subgroup	AVERAGE HOUSEHOLD VMT			
	Work Trip VMT		Total VMT	
	Base	Δ	Base	Δ
1	17.47	-2.65	28.27	-2.57
2	7.52	-1.49	7.52	-1.49
3	11.45	-1.28	22.25	-1.22
4	4.77	-0.42	4.77	-0.42

X

Subgroup Fraction of Total Pop.
.531
.069
.354
.046

=

NORMALIZED HOUSEHOLD VMT			
Work Trip VMT		Total VMT	
Base	Δ	Base	Δ
9.28	-1.41	15.01	-1.36
0.52	-0.10	0.52	-0.10
4.05	-0.45	7.88	-0.43
0.22	-0.02	0.22	-0.02
14.07	-1.98	23.63	-1.91

AVERAGE $= \sum_{\text{Subgroup}} =$ 14.07 | -1.98 | 23.63 | -1.91

Percent Change in VMT	
Work	Total
-15.17	-9.09
-19.81	-19.81
-11.18	-5.5
-8.81	-8.81

	Average ΔVMT		Average VMT				% ΔVMT
Work Trip :	-1.98	÷	14.07	X	100	=	-14.1
Total :	-1.91	÷	23.63	X	100	=	-8.1

V-A. SUMMARY OF CHANGES IN MODAL SHARES

POLICY HOV Lane

Population Subgroup	AVERAGE MODAL SHARE										Fraction of Total Pop.	NORMALIZED MODAL SHARE									
	Drive Alone		Shared Ride		Transit		Other		Vanpooling			Drive Alone		Shared Ride		Transit		Other		Vanpooling	
	B*	R*	B**	R	B	R	B	R	B	R		B	R	B	R	B	R	B	R	B	R
1	.364	.306	.274 .060	.232 .068	.302	.394	0	0	0	0	.531	.193	.162	.145 .032	.123 .036	.160	.209	--	--	--	--
2	0	0	.431 .094	.335 .098	.475	.567	0	0	0	0	.069	0	0	.030	.023	.033	.039	--	--	--	--
3	.364	.316	.274 .060	.256 .065	.302	.363	0	0	0	0	.354	.129	.112	.097 .021	.091 .023	.107	.129	--	--	--	--
4	0	0	.431 .094	.374 .095	.475	.531	0	0	0	0	.046	0	0	.020 .004	.017 .004	.022	.024	--	--	--	--
AVERAGE = $\sum_{\text{Subgroup}}$ =												.322	.274	.292 .063	.254 .070	.322	.401	--	--	--	--

* B=Base
R=Revised

** $\frac{X}{Y}$ X=2,3 Person Carpools
Y=4+ Person Carpools

$$(0.4 \times 9.5 + 0.6 \times 14.5) \times 18{,}743 \times 2 = 468{,}575 \text{ VMT/day}$$

This VMT must be apportioned among the four population subgroups. The total work VMT accounted for by each market segment is given by:

$$VMT_a = F_a \times HHVMT_a \div HHVMT_t \times VMT_t$$

where:

VMT_a = Work VMT for subgroup A

F_a = Fraction of population in subgroup A

$HHVMT_a$ = Household work VMT for subgroup A (from Worksheet I-A)

$HHVMT_t$ = Average Household Work VMT for all subgroups

VMT_t = Total work VMT for all subgroups

The average household work VMT for the corridor ($HHVMT_T$) is calculated by adding the product of HHVMT and F_a for all subgroups:

$$17.47(.531) + 7.52(.069) + 11.45(.354) + 4.77(.046) = 14.07 \text{ miles/day}$$

The subgroup daily work VMT may now be calculated:

$$VMT_1 = \frac{.531 \times 17.47}{14.07} \times 468{,}575 = 308{,}939 \text{ miles/day}$$

Similar calculations for each subgroup yield work trip base VMT which may be used in conjunction with the percent change in VMT figures summarized on Worksheet IV for each subgroup to obtain total VMT changes:

Subgroup	Base Work VMT	Proportional Changes in Work VMT	Revised Work VMT
1	308,979 mi.	-.152	262,014
2	17,283 mi.	-.198	13,861
3	135,005 mi.	-.112	119,884
4	7,308 mi.	-.088	6,665

Similar estimates must be made for non-work VMT as well, but they need only be made for subgroups 1 and 3. Worksheet I-A indicates that the base household non-work VMT for both subgroups 1 and 3 is 10.8 miles. The base total non-work VMT for these groups may be found by simply taking the ratios of base household non-work VMT to work VMT and multiplying by the subgroup work VMT totals above. Worksheet IV then provides the proportional change in non-work VMT for the two subgroups required to develop the following estimates of non-work VMT changes:

Subgroup	Base Non-Work VMT	Proportional Changes	Total Change
1	191,012	+.007	+ 1,337
3	127,341	+ .005	+ 637

The emissions worksheets method (4.1) may now be used to forecast HC and NOx emissions changes in the corridor. Reference to Emissions Tables D.1 through D.6 in Volume I is required.

Worksheet VI-A is used twice to calculate base and revised corridor VMT and the number of trips made by trip purpose using the base and revised VMT by population subgroup as calculated above. The average travel speeds for each population subgroup are assumed to be the same for the base and revised cases. Alternatively, actual average vehicle speeds could be calculated based on the mode split between 4+ person carpools and autos, and knowledge of trip speed and length for each mode. Based on this assumption, start-up and travel emissions may be calculated for the corridor as a whole, rather than for each market segment, using Worksheets VI-C and VI-D. Worksheet VI-B is used to determine the percentage of cold starts for work and non-work trips for the study year. Because parking duration data is not available for the study corridor, Emissions Table D.1 provides the necessary 1982 cold start percentages.

Worksheets VI-C and VI-D are each executed twice, once for the base case, and once for the revised situation. The use of the worksheets is straightforward, using data from the Emissions tables and worksheets as noted. A summer ambient temperature of 75 degrees is assumed based on historical data.

The cold start HC factor for work trips is obtained by simple linear interpolation in Emissions Table D.2. Two dimensional interpolation is required to determine the cold start HC factor for non-work trips. The procedure for accomplishing two (and three) dimensional interpolation is described in Vol. I, Section D.4. The calculations for the study corridor appear below, with steps corresponding to those outlined in Section D.4.

1. Identify bracketing values.

$X_1 = 70, \qquad X_2 = 80$

$Z_1 = 50, \qquad Z_2 = 60$

2. Read emissions factors for bracketing combinations from Table D.2.

Combination	Emission Factor
70 , 50	6.2
70 , 60	6.9
80 , 50	5.7
80 , 60	6.2

3. Compute f_X and f_Z.

$f_X = \frac{75 - 70}{80 - 70} = .5$ (Ambient temperature of 75 degrees)

$f_Z = \frac{57 - 50}{60 - 50} = .7$ (57 percent cold starts)

4. Compute emissions factor.

$$\begin{aligned} e_f = {} & .5 \times .3 \times 6.2 \; + \\ & .5 \times .7 \times 6.9 \; + \\ & .5 \times .3 \times 5.7 \; + \\ & .5 \times .7 \times 6.2 \quad = \underline{6.37} \end{aligned}$$

The value 6.37 is entered for the non-work cold start HC factor on Worksheet VI-C, column 8.

VI-A. INPUT TRAVEL DATA SUMMARY FOR EMISSIONS ESTIMATION

☒ Base Alternative

☐ Revised Alternative

Forecast Year: 1982

Policy: HOV Lane

Population Subgroup	Work VMT (I or IV)[1]	÷	Average Work Trip Distance (miles)(I)	=	Number of One-Way Work Trips	Non-Work VMT (I or IV)	÷	Average Non-Work Trip Distance (miles) (I)	=	Non-Work Trips
1	308,979		(II or I) 14.5		21,309	191,012		3		63,671
2	17,283		14.5		1,192	0		-		
3	135,005		9.5		14,211	127,341		3		42,447
4	7,308		9.5		769	0		0		

$\sum =$ 468,575 TOTAL WORK VMT

$\sum =$ 37,481 TOTAL WORK TRIPS

$\sum =$ 318,353 TOTAL NON-WORK VMT

$\sum =$ 106,118 TOTAL NON-WORK TRIPS

143,599 TOTAL TRIPS

---

[1] Source Worksheets are indicated in parentheses where applicable. VMT and trips on worksheets I and IV in Appendix A must be multiplied by the number of households per population subgroup.

VI-A. INPUT TRAVEL DATA SUMMARY FOR EMISSIONS ESTIMATION

☐ Base Alternative
☒ Revised Alternative
Forecast Year: 1982
Policy: HOV Lane

Population Subgroup	Work VMT (I or IV)[1]	÷	Average Work Trip Distance (miles)(I)	=	Number of One-Way Work Trips		Non-Work VMT (I or IV)	÷	Average Non-Work Trip Distance (miles) (I)	=	Non-Work Trips
1	262,014		14.5		18,070		192,349		3		64,116
2	13,861		14.5		956		0		-		-
3	119,884		9.5		12,619		127,978		3		42,659
4	6,665		9.5		702		0		-		-
$\sum =$	402,424			$\sum =$	32,347	$\sum =$	320,327			$\sum =$	106,775
	TOTAL WORK VMT				TOTAL WORK TRIPS		TOTAL NON-WORK VMT				TOTAL NON-WORK TRIPS

139,122 TOTAL TRIPS

---

[1] Source Worksheets are indicated in parentheses where applicable. VMT and trips on worksheets I and IV in Appendix A must be multiplied by the number of households per population subgroup.

VI-B. COLD START FRACTIONS

☒ Base Alternative

☐ Revised Alternative

Policy: HOV Lane

Subgroup: All

Forecast Year: 1982

1. If Daily Parking Duration Data are Available:

% of Auto Trips by Catalyst-Equipped Vehicles (Table D.1)		% of Auto Trips with Parking Duration 1 hour		% of Auto Trips by Non-Catalyst Equipped Vehicles		% of Auto Trips with Parking Duration 4 hours		% of Auto Trips with Cold Starts
	X		+		X		=	

2. If Daily Parking Duration Data are not Available

% of Work Trip Cold Starts (Table D.2)

90

% Non-Work Trip Cold Starts (Table D.2)

57

VI-C. AUTO START-UP AND EVAPORATIVE EMISSIONS

☒ Base Alternative

☐ Revised Alternative

Policy: HOV Lane

Forecast Year: 1982

Temperature: 75

	Work Trips						Non-Work Trips			
(1) Population Subgroup	(2) % Cold Starts (VI-B)[1]	(3) Trips (IV-A)	Pollutant[2]	From Table[3]	(4) Start-Up Factors	(5) Emissions = Col. 3 X Col. 4 (grams)	(6) % Cold Starts (VI-B)	(7) Trips (VI-A)	(8) Start-Up Factors	(9) Emissions = Col. 3 X Col. 4 (grams)
All	90	37,480	HC(c)	D.2	8.3	311,092	57	106,118	6.37	675,972
			CO(c)	D.3	-	-			-	-
			NOx(c)	D.4	3.5	131,184			3.0	318,354
			HC(h)	D.6	6.0	224,886			6.0	636,708
			HC(c)	D.2						
			CO(c)	D.3						
			NOx(c)	D.4						
			HC(h)	D.6						
			HC(c)	D.2						
			CO(c)	D.3						
			NOx(c)	D.4						
			HC(h)	D.6						

TOTALS

TOTALS $\sum$ Subgroups	Work Trip Start-Up Emissions (grams)	+	$\sum$ Subgroups	Non-Work Trip Start-Up Emissions (grams)	=	Total Start-Up Emissions (grams)
HC	535,978		HC	1,312,680		1,848,658
CO	-		CO			
NOx	131,184		NOx	318,354		449,538

---

[1] Source Worksheets are indicated in parentheses where applicable

[2] (c) indicates cold start factor

(h) indicates hot soak factor

[3] both work and non-work start-up factors obtained from the indicated tables

VI-C. AUTO START-UP AND EVAPORATIVE EMISSIONS

☐ Base Alternative

☒ Revised Alternative

Policy: HOV Lane

Forecast Year: 1982

Temperature: 75

	Work Trips						Non-Work Trips			
(1) Population Subgroup	(2) % Cold Starts (VI-B)[1]	(3) Trips (IV-A)	Pollutant[2]	From Table[3]	(4) Start-Up Factors	(5) Emissions = Col. 3 X Col. 4 (grams)	(6) % Cold Starts (VI-B)	(7) Trips (VI-A)	(8) Start-Up Factors	(9) Emissions = Col. 3 X Col. 4 (grams)
All	90	32,347	HC(c)	D.2	8.3	268,480	57	106,775	6.37	680,156
			CO(c)	D.3	-	-			-	-
			NOx(c	D.4	3.5	113,215			3.0	320,325
			HC(h)	D.6	6.0	194,082			6.0	640,650
			HC(c)	D.2						
			CO(c)	D.3						
			NOx(c	D.4						
			HC(h)	D.6						
			HC(c)	D.2						
			CO(c)	D.3						
			NOx(c	D.4						
			HC(h)	D.6						

TOTALS

TOTALS $\sum$ Subgroups	Work Trip Start-Up Emissions (grams)		$\sum$ Subgroups	Non-Work Trip Start-Up Emissions (grams)		Total Start-Up Emissions (grams)
HC	462,652	+	HC	1,320,806	=	1,783,368
CO			CO			
NOx	113,215		NOx	320,326		433,540

---

[1] Source Worksheets are indicated in parentheses where applicable

[2] (c) indicates cold start factor

(h) indicates hot soak factor

[3] both work and non-work start-up factors obtained from the indicated tables

The NOx factors required by Worksheet VI-C are obtained in a similar manner from Emissions Table D.4. The work factor is obtained directly and the non-work factor requires simple interpolation. The final input to Worksheet VI-C, Hot Soak HC factor, is read directly from Emissions Table D.5 for 1982.

Worksheet VI-D is used to determine travel, or VMT-related, emissions for the base and revised alternatives. For simplicity, average speeds of 20 mph for work trips and 30 mph for non-work trips are assumed. Emissions factors for 1982 and average speeds of 25 and 30 mph may be read directly from Emissions Table D.6 and entered on Worksheet VI-D. Worksheet VI-A supplies the necessary VMT total work and non-work figures for the corridor.

Worksheet VI-E may now be used to summarize the net HC and NOx emission reduction associated with the HOV lane. The data sources for this worksheet are noted for each item. All of the emissions changes are given in grams per day.

I. Interpretation of Results

Large reductions in ozone forming emissions and total VMT are predicted for the proposed combination of carpool and bus enhancements in the corridor. The 67,500 mile reduction in daily work VMT (Worksheet III-1) represents a decrease of more than 14 percent from the current level of 468,375 miles per day. The predicted HC and NOx emissions decreases shown on Worksheet VI-E are each on the order of one-fifth of a ton per day. Although some of the input data items for the analysis procedure represented somewhat rough estimates of existing conditions in the corridor, the magnitude of the predicted impacts on VMT and vehicle emissions

VI-D. AUTO TRAVEL EMISSIONS

☒ Base Alternative

☐ Revised Alternative

Policy: HOV Lane

Forecast Year: 1982

	Work Trips				Non-Work Trips			
(1) Population Subgroup	(2) Average Speed	(3) VMT (VI-A)[1]	(4) Auto Travel Factors (Table D.7)	(5) Emissions = Col. 3 X Col. 4 (grams)	(6) Average Speed	(7) VMT (VI-A)	(8) Auto Travel Factors (Table D.7)	(9) Emissions = Col. 7 X Col. 8 (grams)
All	20	468,575	HC 1.9	890,290	30	318,353	HC 1.3	413,859
			CO –				CO	
			NOx 1.9	890,290			NOx 2.3	732,212
			HC				HC	
			CO				CO	
			NOx				NOx	
			HC				HC	
			CO				CO	
			NOx				NOx	
			HC				HC	
			CO				CO	
			NOx				NOx	
			HC				HC	
			CO				CO	
			NOx				NOx	
			HC				HC	
			CO				CO	
			NOx				NOx	

TOTALS

	$\sum$ Subgroups: Work Trip Travel Emissions (grams)	+	$\sum$ Subgroups: Non-Work Trip Travel Emissions (grams)	=	Total VMT Travel Emissions (grams)
HC	890,290		413,860		1,304,150
CO					
NOx	890,290		732,210		1,622,500

---

[1] Source Worksheets are indicated in parentheses where applicable

VI-D. AUTO TRAVEL EMISSIONS

☐ Base Alternative

☒ Revised Alternative

Policy: HOV Lane

Forecast Year: 1982

	Work Trips				Non-Work Trips			
(1) Population Subgroup	(2) Average Speed	(3) VMT (VI-A)[1]	(4) Auto Travel Factors (Table D.7)	(5) Emissions = Col. 3 X Col. 4 (grams)	(6) Average Speed	(7) VMT (VI-A)	(8) Auto Travel Factors (Table D.7)	(9) Emissions = Col. 7 X Col. 8 (grams)
All	20	402,424	HC 1.9	764,606	30		HC 1.3	416,425
			CO –				CO	
			NOx 1.9	764,606			NOx 2.3	736,752
			HC				HC	
			CO				CO	
			NOx				NOx	
			HC				HC	
			CO				CO	
			NOx				NOx	
			HC				HC	
			CO				CO	
			NOx				NOx	
			HC				HC	
			CO				CO	
			NOx				NOx	
			HC				HC	
			CO				CO	
			NOx				NOx	

TOTALS	Work Trip Travel Emissions (grams)		Non-Work Trip Travel Emissions (grams)		Total VMT Travel Emissions (grams)
$\sum_{\text{Subgroups}}$ HC	764,606	+ $\sum_{\text{Subgroups}}$ HC	416,425	=	1,181,031
CO		CO			
NOx	764,606	NOx	736,752		1,501,358

---

[1] Source Worksheets are indicated in parentheses where applicable

VI-E. SUMMARY OF CHANGES IN EMISSIONS

Revised Alternative

Policy: HOV Lane

Forecast Year: 1982

(1) Population Subgroup		Base Emissions (2) Trip-Related (VI-C)[1]	Base Emissions (3) Travel (VI-D)	Base Emissions (4) Total (Col.2 + Col.3)	Revised Emissions (5) Trip-Related (VI-C)	Revised Emissions (6) Travel (VI-D)	Revised Emissions (7) Total (Col.5+Col.6)	(8) Change in Total Emissions (Col.4-Col.7)	(9) Percent Change in Emissions (Col.8/Col.4) x 100
All	HC	1,848,658	1,304,150	3,152,808	1,783,368	1,181,031	2,964,399	-188,409	-6.0
	CO	-	-	-	-	-	-	-	-
	NOx	449,538	1,622,500	2,072,038	433,540	1,501,358	1,934.898	-137,140	-6.6
	HC								
	CO								
	NOx								
	HC								
	CO								
	NOx								
	HC								
	CO								
	NO_x								

TOTALS

Σ Sub-groups		Total Base Emissions (grams)	Σ Sub-groups		Total Change in Emissions (grams)	Percent Change, Total Emissions
	HC	3,152,808		HC	-188,409	-6.0
	CO			CO		
	NOx	2,072,038		NOx	-137,140	-6.6

---

[1] Source Worksheets are indicated in parentheses where applicable

indicate that significant beneficial impacts can be predicted for the proposal with a high degree of confidence.

In general, the types of mode shifts which were anticipated prior to the analysis are predicted to occur. The corridor-wide average mode share estimates from Worksheet V-A indicate that the major impact of the proposed measures is an increase in bus patronage--on the order of 25 percent. Both drive-alone commuters and carpoolers are predicted to switch to buses, with the overall share for each auto mode decreasing. However, the number of four-person-or-larger carpools is predicted to increase by about 11 percent in response to the greatly improved travel speeds these carpools will enjoy[1]. The combination of lower overall carpool share and higher four carpool share implies an increase in the average size of carpools in the corridor. From the impacts predicted using the manual analysis techniques, it can be seen that the proposal will achieve its major goals of decreasing fuel consumption and vehicle emissions through increases in the use by commuters of large carpools and buses.

The air quality and fuel conservation potential of the planned measures as generally proposed is quite certain; further, more detailed analysis is not required to establish the desireability of pursuing implementation. However, in the project's later planning stages, it may be desirable to do a more detailed analysis to select the most attractive detailed implementation plan. This analysis would necessarily be at a much more specific and complex level, requiring the use of computer-based techniques such as SRGP.

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[1] Note that all percentage figures apply only to trips between the study corridor and the CBD and fringe areas. On a regionwide basis, percentage changes will be much smaller.

CASE STUDY II

DOWNTOWN AUTO RESTRICTED ZONE

CASE STUDY II: DOWNTOWN AUTO RESTRICTED ZONE

A. Problem Presentation

The major retail and office employment center of a large eastern city experiences recurring heavy traffic congestion throughout much of the day. During the peak travel period, traffic tie-ups in the area lead to congestion problems throughout the central business district of the city. This congestion contributes to the poor air quality of the metropolitan area as a whole (which is in violation of the ozone health standard), and is the major cause of high levels of carbon monoxide in the CBD. There is also a general consensus within the downtown business community that the current traffic situation within the area is contributing to declining retail sales and a general deterioration of the area's shopping environment.

B. Proposed Transportation Measures

In response to the congestion problems in the area and the desires of retailers to improve shopping conditions, a plan incorporating the removal of traffic from sections of two major streets in the shopping district has been developed. The plan also provides for the rerouting of auto traffic around the auto restricted zone (ARZ) and new routings for buses on the auto restricted streets and reserved lanes on streets adjacent to the ARZ. The plan has reached a high level of maturity including a detailed assessment of the likely changes in the traffic flows on streets in the CBD and the specification of bus routings and stops in the area. However, no analysis of how the proposed measures will affect the mode choices of travellers to the ARZ or vehicle emissions in the metropolitan area has been conducted. Additionally, there is some controversy over whether a free shuttle bus service proposed by some of the retailers should be provided between the ARZ and the parking lots and major transit terminals which surround it. A quick analysis is necessary to determine the relative air quality impacts of the planned ARZ with and without the proposed shuttle bus service.

Work and non-work trips to the ARZ must be considered in the analysis since the proposed changes will have a direct impact on the relative levels of service offered by the different modes for all trips. The auto restrictions proposed under the ARZ plan will tend to increase in-vehicle travel time for all auto users destined to the immediate area proposed for auto restriction. Increased circuity due to the necessity for autos to travel around, rather than through, the auto restricted area will be primarily responsible for the increase in travel time for auto trips. Out of vehicle travel time for both auto and transit will be reduced because of the ARZ. The removal of traffic from the ARZ area will lead to easier and faster walking for all pedestrians, while the routing of bus lines directly into the area will shorten the walk from the bus stop to the final destination for transit riders. Since on-street parking is currently not available on the proposed auto restricted streets, and access will continue to be provided to all off-street parking facilities, walking distances for auto travellers will not change. If shuttle bus service is provided to the parking garages and transit terminals, further out-of-vehicle travel time reductions will be experienced by both auto and transit users.

In summary, the following level-of-service changes are associated with the ARZ proposal:

Transportation Measure	Level-of-Service Impact
1. Removal of Autos from Shopping District Streets	- Increased in vehicle travel time (IVTT) for auto users to the ARZ
	- Reduced out-of-vehicle travel time (OVTT) for auto users
	- Reduced OVTT for transit users
2. Free Shuttle Service	- Reduced OVTT for auto users
	- Reduced OVTT for transit users

All of the proposed actions will be taken by 1982. Because the short-term effects of the auto restrictions are of primary interest, 1982 is selected as the analysis year.

The proposed measures are expected to affect both work and non-work travel to the ARZ. The extra access time for auto trips is expected to lead to a shift to transit, which already carries the majority of the area's workers. Improved (reduced) walk times from transit stops to employers in the area will further improve the service offered by transit relative to auto.

The overall effect of the proposed measures on the number of people travelling to the ARZ for non-work purposes is uncertain. Some argue that the improved walking conditions associated with the removal of traffic from the area's streets will attract more people. Others contend that making the area more difficult to reach by auto will make it less attractive than other shopping areas in the city, causing an overall reduction in the numbers of non-work trips to the area.

C. Selection of Analysis Technique

Because the removal of autos from the streets in the core of the city's retail center has been accepted as a desireable action and since the ARZ plan has reached a fairly high level of detail with respect to auto traffic and bus routing, a detailed demand and air quality analysis is not required. A simple comparison of the impacts of the ARZ with and without the proposed shuttle service, yielding order of magnitude estimates of the emissions changes likely to occur under each scenario, will be sufficient to make a decision on the provision of the shuttle service. Because the amount of time allocated to the analysis is limited, and a programmable calculator is readily available, the program 3MODE(VAN)-AGG (2.2.3)[1] is selected for computing the mode share and VMT impacts of the two ARZ scenarios. The manual emissions worksheets (4.1) and auto fuel consumption and operating costs method (4.2) are used to develop air quality impact estimates based on the predicted VMT changes. In addition, systematic data analysis methods (2.1.3) are used to specify base case conditions.

A non-standard application of the calculator program is necessary for the analysis of non-work trips. A model of joint destination and mode choice for non-work trips is used in place of the standard work trip model incorporated into the calculator program. This is accomplished by replacing the default model coefficients in the program with user-supplied coefficients based on the non-work model. The worksheets for preparing input data for the program and for summarizing the calculator outputs are also used in a non-standard way, which will be described in subsequent sections.

---

[1] The section numbers following specified analysis methods refer to the location of their description in Volume I.

D. Overview of the Analysis

The analysis of the effects of the ARZ on downtown and region-wide air quality requires five basic steps:

Step 1 - Identify components of each policy scenario (shuttle and non-shuttle)

Step 2 - Segment the affected population into homogeneous sub-groups or market segments and develop base data for each.

Step 3 - Estimate and quantify the transportation level-of-service impacts of each scenario for each trip type.

Step 4 - Estimate new mode shares and VMT using the 3MODE(VAN)-AGG program.

Step 5 - Estmiate changes in vehicle emissions using the manual auto emissions worksheets.

The relationship between these steps is shown in the flow chart of Figure II-1. The first three steps involve the preparation of data for input to 3MODE(VAN)-AGG in step 4. Changes in the level-of-service experienced by each of the market segments identified in step 2 must be determined separately for each of the two ARZ scenarios, while the rest of the input data is identical for the shuttle and non-shuttle alternatives.

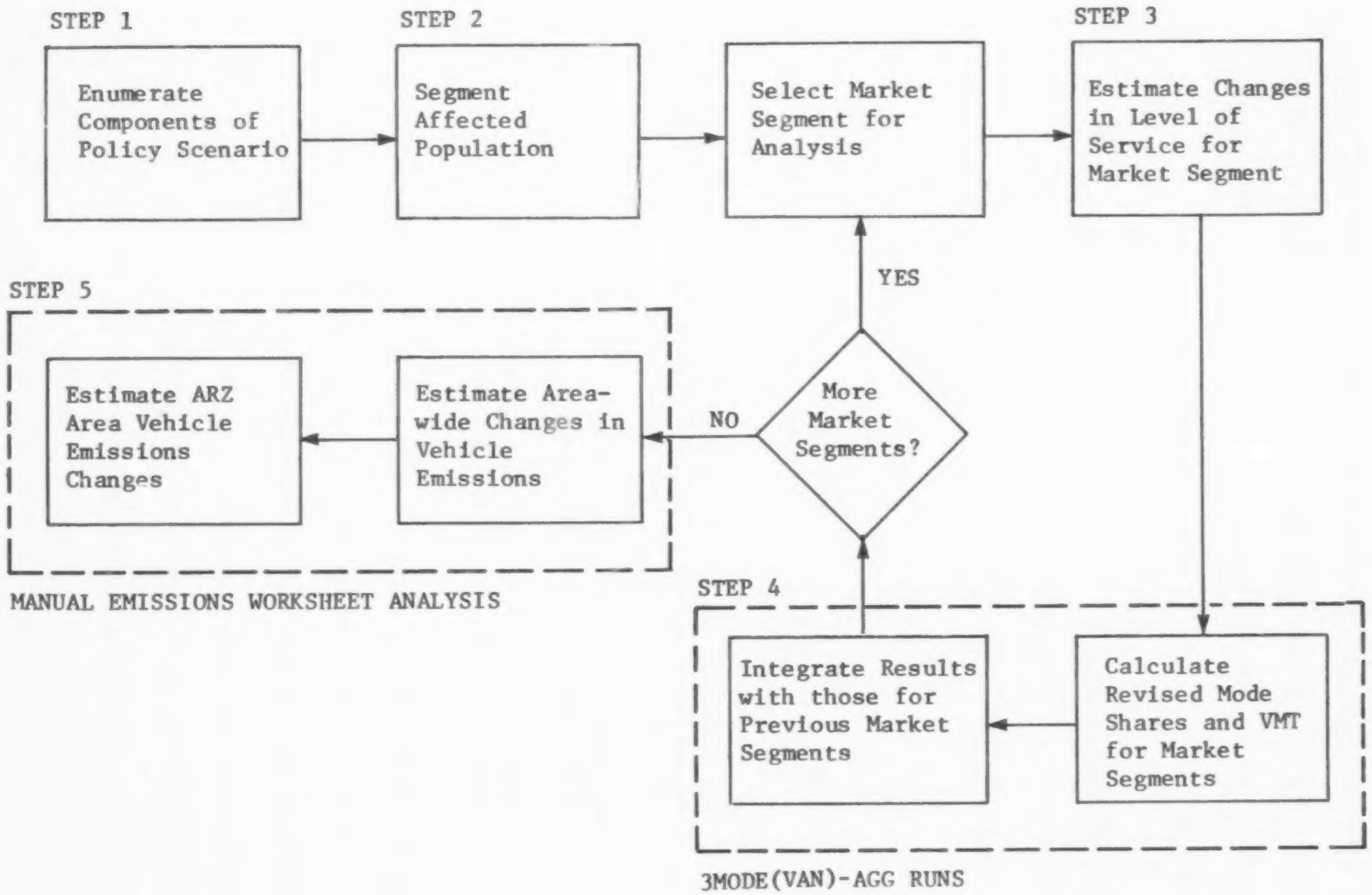
STEP 1
Enumerate Components of Policy Scenario
STEP 2
Segment Affected Population
Select Market Segment for Analysis
STEP 3
Estimate Changes in Level of Service for Market Segment
YES
More Market Segments?
NO
STEP 5
Estimate Area-wide Changes in Vehicle Emissions
Estimate ARZ Area Vehicle Emissions Changes
MANUAL EMISSIONS WORKSHEET ANALYSIS
STEP 4
Calculate Revised Mode Shares and VMT for Market Segments
Integrate Results with those for Previous Market Segments
3MODE(VAN)-AGG RUNS

FIGURE II-1

Steps in Analysis of ARZ Policy Scenarios
(All steps repeated for each scenario)

The calculator program provides estimates of the changes in VMT by travel mode for work and non-work trips under each scenario. These estimates are then used in the step 5 analysis of vehicle emission impacts.

E. Defining the Scope of the Analysis

The relevant components of each policy scenario were identified in section B above; therefore, step 1 of the analysis has been completed. Step 2 involves determining how detailed the analysis should be (the more market segments identified, the more detailed and complex the analysis becomes). Budget limitations for the analysis, the availability of data pertaining to different population groups and the desired accuracy of the predictions developed during the analysis are the major considerations in choosing the scope and level of detail of the analysis.

For the analysis of the ARZ proposal, two levels of distinction between the affected travelers were used. Work and non-work trips to the ARZ are analyzed separately, and for each trip type, households with and without autos available for their trip are considered independently. This categorization of travellers leads to the following four market segments:[1]

- Workers with the drive alone mode available
- Workers without the drive alone mode available
- Non-work travellers with an auto available
- Non-work travellers with no auto available

---

[1] The non-work model to be used in the analysis has only two modes: auto and transit. Non-work travellers without autos must use transit. However, workers in the ARZ can use the shared-ride mode regardless of the availability of the auto to them.

The changes in level-of-service associated with the three ARZ scenarios will potentially affect the mode choices of both work and non-work travellers. A distinction between work and non-work trips is crucial to the development of accurate impact estimates because of the different choices available to each. The attractiveness of the ARZ is reflected in part by the level of transportation service available, and will determine the total number of non-work trips destined to the area. On the other hand, the volume of work trips is fixed in the short-run, being determined by the total employment in the area. Thus, in analyzing non-work trips both destination and mode choice must be determined, while only mode choice is of interest for work trips.

Separating the population into groups with and without the drive alone or auto mode available leads to greater accuracy in the prediction of revised mode shares. This distinction is particularly important for the analysis of this ARZ proposal because of the high proportion of those living in the city who do not own autos (18 percent).

F. Input Data Development

Worksheets C-1 and C-2 for the 3MODE(VAN)-AGG procedure define the data required for input to the program for each market segment. Much of the information required for this analysis is available from detailed planning studies conducted for the ARZ, and transportation system data bases developed as part of the metropolitan area's on-going transportation planning process. Such data is typically available for a large city with a well developed metropolitan transit system.

Base Data

Hourly total person trip tables for the 1982 analysis year provide most of the base data required for worksheet C-1[1]. Average trip lengths were calculated using the trip tables at the district level and a map of the urban area (to determine district-to-district distances). Annual household income is not required in the analysis since none of the measures involve changing the cost of any of the modes. However, the calculator program requires that the default value "1" be entered for income. No information was available on average carpool size for trips to the ARZ area, so the default value of 2.5 (the national average for carpool size) is assumed. The total population of the two work trip market segments was determined by summing all of the AM peak period and 25 percent of the PM peak period ARZ-bound trips, and then apportioning these trips among auto owning and non-auto owning households.[2]

Figure II-2 shows a typical distribution of auto ownership by 1970 income level for a large city with a well developed transportation system. For the metropolitan area under study, the 1972 U.S. Census County and City Data Book reported the following distribution of households by income level:

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[1] If a trip table for the region was not readily available, the quick response urban travel estimation techniques (2.1.2) could be used to determine the total number of work and non-work trips to the area.

[2] All of the AM peak period trips and a smaller proportion of the PM peak period trips to the ARZ are assumed to be work trips.

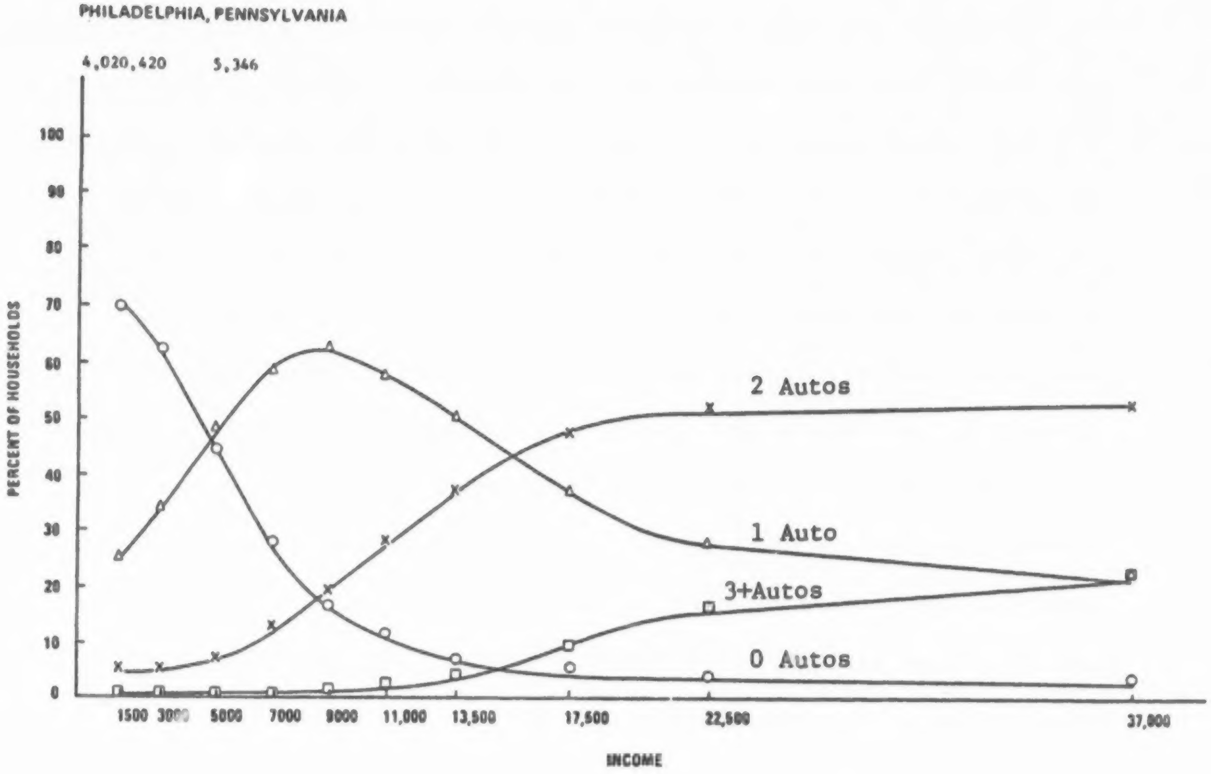

FIGURE II-2

Auto Ownership Distribution

Household Annual Income Range	Percentage of Total Households
Under $3,000	6.1
$3,000 - 4,900	6.8
$5,000 - 9,999	18.7
$10,000 - 14,999	29.8
$15,000+	30.1

The overall proportion of households owning no autos may be calculated by reading the average percentage of zero auto owning households for each income level from Figure II-2, and then multiplying the percentage by the proportion of all households in the income bracket:

$$\overset{\underline{\text{Income Under \$3,000}}}{.65\left(\frac{\text{0 Auto HH}}{\text{HH<3K}}\right) \times \frac{\text{.061 HH<3K}}{\text{Total HH}}} + \overset{\underline{\text{\$3-5,000}}}{(.535)\ (.068)} + \overset{\underline{\text{\$5-7,000}}}{(.370)\ (.087)}$$

$$\overset{\underline{\text{\$7-10,000}}}{(.210)\ (.185)} + \overset{\underline{\text{\$10-15,000}}}{(.085)\ (.298)} + \overset{\underline{\text{\$15,000+}}}{(.030)\ (.301)} = .181$$

The 18 percent zero auto owning proportion was applied to the total work trip volume of 128,748 round trips per day to obtain the market segment populations for sub-groups 1 and 2 on the Worksheet C-1.

Potentially, any of the urban area's 3,654,200 residents could travel to the ARZ for a non-work purpose. Therefore, the entire population of the region classified by auto ownership, forms market segments 3 and 4. As with workers, 18% of the non-work population is assumed to have no auto available.

Vanpools do not operate to the ARZ area now, and none are expected to start up as a result of the auto restrictions. However, the default values shown on worksheet C-1 for average vanpool size and vanpool circuity factor must be entered into the calculator program. They will not be used in any of the internal calculations or subsequent analysis steps, however.

Base Mode Shares

Work Trips

For market segments 1 and 2 combined (all workers in the ARZ area), the total number of trips made to the downtown area by transit may be determined from alighting counts taken on each of the bus routes terminating in the ARZ and each of the six subway stops serving the area, during the a.m. and p.m. peak periods. Once again all of the a.m. peak period and one-quarter of the p.m. peak period trips downtown are assumed to be work trips. Counts of transit passengers to downtown by hour were conducted recently as part of the planning process for the ARZ proposal. According to the counts, the total number of daily transit trips classified as work trips is 94,872--out of 128,748 total work trips. The aggregate transit share for all workers is then 73.7 percent, leaving an auto share of 26.3 percent. Data from annual screenline traffic counts indicate that 66 percent of the persons entering the CBD by auto are auto drivers and 34 percent are auto passengers.[1] The aggregate auto driver and auto passenger mode shares are then:

---

[1] If no auto occupancy data were available for the study area, the quick response urban travel estimation techniques (2.1.2) could have been used to determine carpooling activity.

$$\text{Auto Driver Share} = .263 \text{ (auto share)} \times .660 \left(\frac{\text{Auto drivers}}{\text{Auto users}}\right) = .174$$

$$\text{Auto Passenger Share} = .263 \times .340 = .089$$

For use in the calculator program analysis, these mode shares must be converted to drive alone and shared ride shares. The following formulas may be used for this conversion:

$$\text{Drive Alone Share} = \text{Auto Driver Share} - \frac{\text{Auto Passenger Share}}{\text{(Average Carpool Size -1)}}$$

$$\text{Shared Ride Share} = \text{Auto Passenger Share} + \frac{\text{Auto Passenger Share}}{\text{(Auto Carpool Size -1)}}$$

Assuming the national average carpool size of 2.5, and using the above auto driver and passenger shares yields:

$$\text{Drive Alone Share} = .174 - \frac{.089}{(2.5-1)} = .114$$

$$\text{Shared Ride Share} = .089 + \frac{.089}{(2.5-1)} = .149$$

Because those not owning autos must have a zero share for the drive alone mode, the mode shares of the two market segments making up the work trip population must be different. To convert from total population mode shares to market segment mode shares, the following formulas (based on the assumption that the ratio of transit riders to carpoolers is the same for the non-auto owning sub-group as the entire population) are used:

$$DA_o = 0 \qquad SR_o = \frac{SR_t}{SR_t + T_t} \qquad T_o = \frac{T_t}{SR_t + T_t}$$

$$DA_1 = \frac{DA_t}{F_1} \qquad SR_1 = \frac{SR_t - SR_oF_o}{F_1} \qquad T_1 = \frac{T_t - T_oF_o}{F_1}$$

where DA_o = Drive alone share for households without autos
SR_o = Shared ride share for households without autos
T_o = Transit share for households without autos
DA_1 = Drive alone for households with autos
SR_1 = Shared ride share for households with autos
T_1 = Transit share for household with autos
DA_t = Drive alone share for all households
SR_t = Shared ride share for all households
T_t = Transit shares for all households
F_o, F_1 = Fraction of household without and with autos

The calculations are crried out sequentially, with the mode shares for households without autos being determined first. For the downtown workers the resulting mode shares are:

$$DA_o = 0 \qquad SR_o = \frac{.149}{.149 + .737} = .168$$

$$T_o = \frac{.737}{.149 + .737} = .832 \qquad DA_1 = \frac{.114}{.82} = .139$$

$$SR_1 = \frac{.149 - .165(.18)}{.82} = .145 \qquad T_1 = \frac{.737 - .832(.18)}{.82} = .716$$

These shares are entered on Worksheet C-1 for subgroups 1 and 2.

Non-Work Trips

Although worksheet C-1 calls for base work trip modal shares, it may be used to record non-work trip making data for input to the non-work model to be used in this analysis. Because the model predicts changes in mode share for auto and transit only, only these modes need to be considered. The model predicts changes both in the mode choice of travellers to the CBD, and the absolute volume of non-work trips to the area as a result of the auto restrictions. The base mode shares reported on Worksheet C-1 for non-work trips must, therefore, reflect the existing mode shares and the proportions of the region-wide non-work trips which are bound for the study area. This is accomplished by using the "other" mode share column to record the proportion of all of the urban area non-work trips which are not bound for the study area (regardless of mode). The drive alone and transit columns of Worksheet C-1 then reflect both the total volume and mode share of non-work trips to the area.

The 1980 trip tables by hour (alternatively the quick response urban travel techniques (2.1.2) could be used) indicate that 5 percent of the non-work trips in the region were destined to the downtown area. Therefore, the "other" mode share for subgroups 3 and 4 is .95. Transit alighting counts in the area and the person trip tables show that the overall non-work transit share is 59 percent. Employing an analysis similar to that used to determine the market segment mode shares for work trips, the following shares were calculated for non-work trips:[1]

---

[1] For simplicity, the non-auto owning households were assumed to have a zero non-work auto mode share. However, a non-zero share for these households could be assigned to reflect their use of carpools for non-work trips. This share could be determined from census data, or could be calculated from a known shared ride and drive alone mode split for non-work trips using adjustments similar to those used above to determine the work trip mode splits for households without autos.

Households without Autos:
    Auto Share - 0%
    Transit Share - 100%

Households with Autos:
    Auto Share 50%
    Transit Share - 50%

Multiplying these shares by the ARZ area's 5% share of total non-work trips yields the base mode shares recorded on Worksheet C-1. (The auto share is recorded in the Drive Alone column.)

Changes in Level-of-Service

Step 3 of the analysis procedure involves quantifying the level-of-service impacts of the proposed auto restrictions in terms of changes in in-vehicle and out-of-vehicle travel time by mode for the shuttle and non-shuttle scenarios. Worksheet C-2 is used to record the level-of-service changes in a format for input to 3MODE(VAN)-AGG.

Auto Trips[1] - In order to determine the average impact of the auto restrictions on in-vehicle travel time for autos, peak and off peak trips made to the area by auto were classified (using the 1980 trip table, and counts at entry points to the CBD) according to entry location and destination point (parking location) within the CBD. The analysis zones used to define the entry and destination points of CBD trips are shown in Figure II-3. Any of the numbered zones were considered potential entry locations and all zones were potential destinations for

---

[1] The drive alone and carpool modes will experience identical level-of-service changes. Therefore, in making estimates of changes in LOS, they are treated together. In recording the estimated LOS changes on Worksheet C-2, identical entries will be made for the drive alone and carpool modes.

ARZ Base Data

WORKSHEET C-1

BASE DATA

POLICY: Downtown ARZ

Population Subgroup	Average round Trip Length (mi)	Annual Household Income ($)	Average Carpool Size	Population	Average Vanpool Size	Vanpool Circuity Factor	Base Work Trip Modal Shares				
							Drive Alone	Carpool	Transit	Vanpool	Other
1. Work Trips All Modes	16	[1]*	[2.5]	105,573	[10]	[1.5]	.139	.145	.716	0	0
2. Work Trips No Drive Alone	16	[1]	[2.5]	23,175	[10]	[1.5]	0	.168	.832	0	0
3. Non-Work All Modes	16	[1]	[2.5]	3,096,780	[10]	[1.5]	.025	0	.025	0	.95
4. Non-Work No Auto	16	[1]	[2.5]	557,420	[10]	[1.5]	0	0	.050	0	.95

*[ ] = Default Value

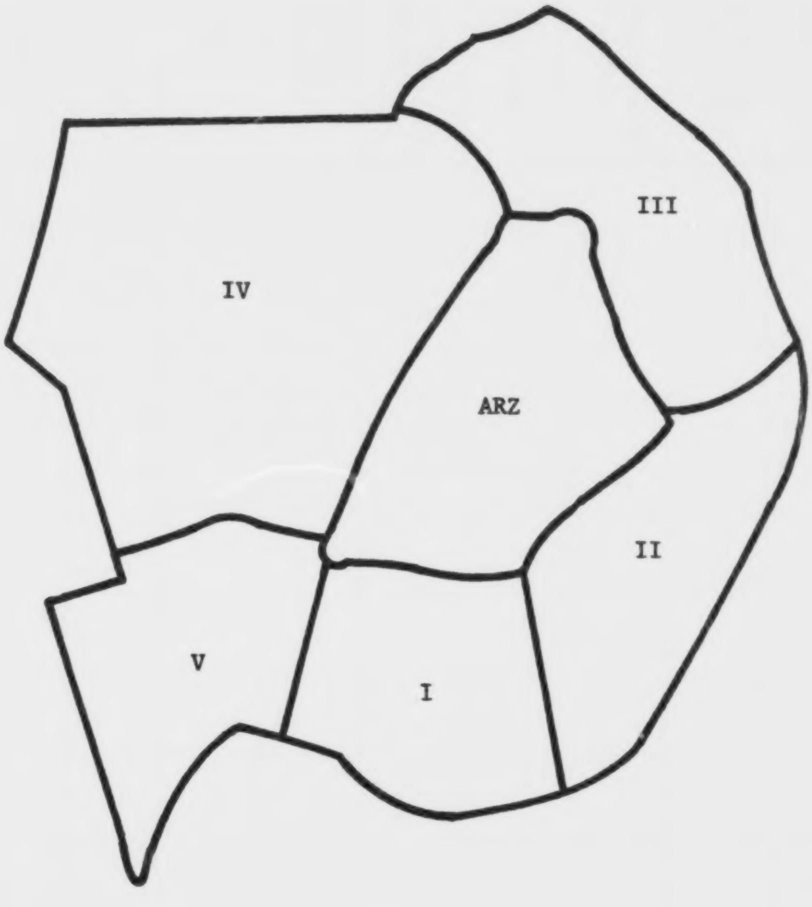

FIGURE II-3

CBD Entry and Destination Zones

auto trips. Changes in the routing of auto trips for each zone pair were determined by examining the new traffic flow patterns (one-way streets, streets closed to autos, etc.) included in the ARZ plan. Entry and destination point pairs with significant auto delays due to more circuitous routing are identified below, along with the estimated delay to autos and the proportion of the total peak period downtown-bound auto person-trips represented by trips between those zones.

Zone Pair	Delay in Minutes (round trip)	Proportion of Total Peak Hour Downtown Auto Trips
I-ARZ	2.0	.043
II-IV	0.5	.069
III-I	3.0	.006
III-V	3.0	.007
III-ARZ	2.0	.020
IV-II	0.5	.069
IV-ARZ	2.0	.021
V-III	3.0	.006
I-III	3.0	.006

A similar table is required for non-work auto trips. Multiplying the round trip delay for each zone pair by the percentage of total auto trips made between the zones and summing over all zone pairs yields the average in-vehicle travel time increase for CBD-bound auto trips (Δ IVTT) as recorded on Worksheet C-2 for the shuttle and non-shuttle alternatives:[1]

---

[1] These IVTT increases for auto trips are not affected by the provision of shuttle bus service since the time on the shuttle is considered to be out-of-vehicle travel time.

Work = + .314 min

Non-work = +1.258 min

Improved walking conditions will reduce out-of-vehicle travel time (OVTT) for all auto trips bound for the ARZ. The CBD entry point and destination trip table shows that 8.4 percent of all CBD auto work trips and 33.7 percent of non-work auto trips are bound for the immediate ARZ area. Average round-trip walk time savings are estimated at 1.0 minute for work trips, and 1.5 minutes for non-work trips, leading to net OVTT savings of .084 minutes for work trips and .506 minutes for non-work trips with no shuttle service.

The shuttle service is estimated to lead to 3.5 minutes in out-of-vehicle travel time savings for those who use it. In previous analyses, it was estimated that 8.5 percent of the downtown-bound auto work trips would use the shuttle service. However, only 40 percent of the ARZ-bound auto travellers will be served by the shuttle (the remaining 50 percent will still save 1.0 minutes). The overall average OVTT savings for the shuttle alternative may be calculated:

$$.085 \, \frac{\text{shuttle trips}}{\text{total trips}} \cdot 3.5 \, \begin{matrix}\text{shuttle}\\ \text{savings}\end{matrix} + .6 \, \frac{\text{ARZ non-shuttle}}{\text{All ARZ}} \cdot$$

$$.085 \, \frac{\text{All ARZ}}{\text{total trips}} \cdot 1.0 \, \begin{matrix}\text{ARZ walk}\\ \text{savings}\end{matrix} = .348 \text{ minutes}$$

The corresponding calculation for non-work auto trips is:

$$.171\ \frac{\text{shuttle trips}}{\text{total trips}}\ \text{x}\ 3.5\ \text{minutes} + .3\ \frac{\text{ARZ non-shuttle}}{\text{All ARZ}}\ \text{x}$$

$$.337\ \frac{\text{ARZ trips}}{\text{total trips}}\ \text{x}\ 1.5\ \text{minutes} = .750\ \text{minutes}$$

(Due to parking location differences for work and non-work trips, a higher proportion of non-work auto trips will be served by the shuttle.) The above IVTT and OVTT changes are the only auto level-of-service impacts anticipated for the ARZ proposal.

Transit Trips

In-vehicle travel time for transit is not anticipated to change appreciably due to the ARZ measures. However, significant OVTT savings are anticipated for both work and non-work trips bound to the ARZ areas for the non-shuttle scenario. Hourly alighting counts at the transit stops within the CBD indicate that for both work and non-work trips, 26.8 percent of the transit passengers bound for downtown locations are travelling to the immediate ARZ area. The combined round trip OVTT savings associated with easier walking in the ARZ and shorter walks due to new bus stop locations within the ARZ are estimated to be approximately two minutes, leading to an average CBD transit OVTT reduction of; .268(2)=.532 minutes. This figure is entered on worksheet C-2 for all market segments for the non-shuttle alternative.[1]

It is expected that approximately 6.5 percent of the CBD bound transit passengers will use the proposed shuttle, enjoying a 3.5 minute OVTT savings. None of these shuttle users will be destined to the ARZ,

---

[1] Unlike auto trips to the area, transit trip-making to the downtown area is similar for work and non-work trips.

however, because transit stops will be located directly on the auto restricted streets. The total transit OVTT reduction for the shuttle alternative is therefore estimated to be; .532 + .065(3.5) = .762 minutes. All market segments on Worksheet C-2 will experience this average transit OVTT savings under the shuttle scenario.

Only travel time changes are expected to occur as a result of the proposed auto restrictions. No travel cost impacts are associated with either the shuttle or non-shuttle alternative. Because the drive alone and carpool impacts are identical, and vanpooling is not expected to occur as a result of the ARZ, no further level of service change estimates or entries on Worksheet C-2 are required.

G. Description of Model Application

Four runs of the calculator program 3MODE(VAN)-AGG are required to estimate new mode splits and VMT for the two ARZ scenarios, one each for work and non-work trips for each scenario. The program runs are straightforward, using none of the optional subroutines. The non-work runs involve the use of user-supplied mode choice coefficients, which were derived from a joint choice model of shopping trip frequency, destination, and mode choice. The work and non-work runs for the non-shuttle alternative are described in detail below. The runs for the shuttle scenario analysis are identical, except for differences in the level of service changes as noted on Worksheet C-2 for the shuttle option.

WORKSHEET C-2 Level-of-Service Changes: Non-Shuttle Alternative

POLICY: Downtown ARZ Non-Shuttle Alternative

CHANGES IN TRANSPORTATION LEVEL OF SERVICE

(all data represent round trips)

Population Subgroup *	Drive Alone			Transit			Carpool				Vanpool			
	In-Vehicle Travel Time $\Delta IVTT_{da}$ (min.)	Out-of-Vehicle Travel Time $\Delta OVTT_{da}$ (min.)	Out-of-Pocket Travel Cost $\Delta OPTC_{da}$ (¢)	In-Vehicle Travel Time $\Delta IVTT_t$ (min.)	Out-of-Vehicle Travel Time $\Delta OVTT_t$ (min.)	Out-of-Pocket Travel Cost $\Delta OPTC_t$ (¢)	In-Vehicle Travel Time $\Delta IVTT_{sr}$ (min.)	Out-of-Vehicle Travel Time $\Delta OPTC_{sr}$ (min.)	Out-of-Pocket Travel Cost $\Delta OPTC_{sr}$ (¢)	Carpool Promotion & Matching Incentives (0,1)	In-Vehicle Travel Time $\Delta IVTT_{sr}$ (min.)	Out-of-Vehicle Travel Time $\Delta OPTC_{sr}$ (min.)	Out-of-Pocket Travel Cost $\Delta OPTC_{sr}$ (¢)	Vanpool Promotion & Matching Incentives (0,1)
1	.314	-.084	0	0	-.536	0	.314	-.084	0	0	.314	-.084	0	0
2	0	0	0	0	-.536	0	.314	-.084	0	0	.314	-.084	0	0
3	1.285	-.506	0	-	-.536	0	0	0	0	0	0	0	0	0
4	0	0	0	0	-.536	0	0	0	0	0	0	0	0	0

*
1 - Work Trips, All Modes
2 - Work Trips, No Drive Alone
3 - Non-Work, All Modes
4 - Non-Work, No Auto

Work Trips

Two passes through the calculator program are used to estimate the combined impact of the ARZ on downtown-bound workers with and without autos available for their trip. Worksheet C-4 is used to prepare the input data from Worksheets C-1 and C-2 for direct input to the Calculator. One pass through the program is described in detail as an example of the required order for calculation steps.

Because user supplied coefficients are not used for the work trip analysis, the first input value required is defined by Step 4 on Worksheet C-4. Market segment data from Worksheet C-1 is entered for market segment 1. The optional carpool subroutine is not used in this run, so Step 6 defines the next set of required input data--base mode shares for market segment 1. The level-of-service changes estimated for the non-shuttle alternative and market segment 1 (Worksheet C-2) are then entered under Step 8 on Worksheet C-4. Note that the changes for drive alone and carpool are identical, and that "0" is recorded for all LOS variables not affected by the ARZ proposal. These are the only program steps requiring input data. Data may now be entered into the programmable calculator, and market segment 1 analyzed.

After the program is read into the calculator, key "A" is pressed to initialize the program. Beginning at Step 4, data items are entered sequentially in the exact order they appear on Worksheet C-4. Key "R/S" is pressed between each item to enter it into the program. Data entry continues through step 6e after which "R/S" is pushed. The calculator will display and print the average number of autos used per worker in the market segment at this point. "R/S" is pressed a second time, and the base total VMT is displayed and printed. Step 8 is begun by pressing

WORKSHEET C -4 PROGRAM STEPS

639.39

(3MODE(VAN)-AGG-2(B)/7900110/ESE)

ARZ, Non-Shuttle:
Work Trips (DA AVAIL)

USER INSTRUCTIONS

STEP	PROCEDURE	ENTER	PRESS			DISPLAY
1	Read card(s) - partitioning is 639.39					
2	Initialize Storage Registers and store default Coefficients		A			.29
	If default coefficients are used, skip to STEP 4	GO TO STEP	4			
3	OPTIONAL - Enter user-supplied coefficients					
3a	coefficient of IVTT-DA mode	θ_1DA =	STO	00		
3b	coefficient of OVTT/DIST-DA mode	θ_2DA =	STO	01		
3c	coefficient of OPTC/Y-DA mode	θ_3DA =	STO	02		
3d	coefficient 4-DA mode	θ_4DA =	STO	03		
3e	coefficient 5-DA mode	θ_5DA =	STO	04		
3f	coefficient of IVTT-SR mode	θ_1SR =	STO	05		
3g	coefficient of OVTT/DIST-SR mode	θ_2SR =	STO	06		
3h	coefficient of OPTC/Y-SR mode	θ_3SR =	STO	07		
3i	coefficient of incentives-SR mode	θ_4SR =	STO	08		
3j	coefficient 5-SR mode	θ_5SR =	STO	09		
3k	coefficient of IVTT-T mode	θ_1T =	STO	10		
3l	coefficient of OVTT/DIST-T mode	θ_2T =	STO	11		
3m	coefficient of OPTC/Y-T mode	θ_3T =	STO	12		
3n	coefficient 4-T mode	θ_4T =	STO	13		
3o	coefficient 5-T mode	θ_5T =	STO	14		
	IF A MISTAKE IS MADE, BEGIN AGAIN AT STEP 3a					
4	Enter market segment data (from worksheet C-11)					
4a	round trip distance in miles ≠ 0	DIST= 16	R/S			
4b	household average annual income in \$ ≠ 0	Y = 1	R/S			
	enter "1" if income is not needed for this segment.					
4c	Average carpool occupancy ≠ 0	OCC_{CP}= 2.5	R/S			
	Default = 2.5					
4d	Market segment population	POP =105573	R/S			

WORKSHEET C-4
(continued)
(3MODE(VAN)-AGG-2(B)/790110/ESE)

USER INSTRUCTIONS

STEP	PROCEDURE	ENTER	PRESS			DISPLAY
4e	Average vanpool occupancy ≠ 0 default -- 10	OCC_{VP} = 10	R/S			
4f	Vanpool circuity factor ≠ 0 default -- 1.5	CIRC = 1.5	R/S			
	If a mistake is made, press $\boxed{C}$ and begin with STEP 4a					
	If carpool subroutine is not used, go to STEP 6	GO TO STEP	6			
5	OPTIONAL - Carpool Subroutine (data from worksheet C-3)		2nd	C'		38
5a	Enter average occupancies of two classes of carpools:					
	1. Average occupancy carpool class 1	OCC_{CP1}= ___	R/S			
	2. Average occupancy carpool class 2	OCC_{CP2}= ___	R/S			
5b	Enter level of service and mode share data					
	1. ΔIVTT - carpool class 1	Δ = ___	R/S			
	2. ΔOVTT - carpool class 1	Δ = ___	R/S			
	3. ΔOPTC - carpool class 1	Δ = ___	R/S			
	4. ΔINCENT - carpool class 1 (0/1)	Δ = ___	R/S			
	5. Δ_5 - carpool class 1**	Δ = ___	R/S			
	6. carpool class 1 share as a fraction of all carpools *	S_{CP1}= ___	R/S	2^{nd}	E'	
	If a mistake is made, press $\boxed{C'}$ and begin with STEP 5a					
	7. ΔIVTT- carpool class 2	Δ = ___	R/S			
	8. ΔOVTT - carpool class 2	Δ = ___	R/S			
	9. ΔOPTC- carpool class 2	Δ = ___	R/S			
	10. Δ INCENT - carpool class 2 (0/1)	Δ = ___	R/S			
	11. Δ_5 - carpool class 2**	Δ = ___	R/S			
	12. carpool class 2 share as a fraction of all carpools*	S_{CP2}= ___	R/S			
	If a mistake is made, press $\boxed{C'}$ and begin with STEP 5a					

* These two values should sum to 1.0

** If default coefficients are used, these Δ's must equal zero.

WORKSHEET C-4

(continued)

(3MODE(VAN)-AGG-2(B)/790110/ESE)

USER INSTRUCTIONS

STEP	PROCEDURE	ENTER	PRESS			DISPLAY
5c	carpool subroutine results:					
	1. New average occupancy for all carpools		R/S			*OCC_{CP} = ______
	2. New carpool change in level of service (for all carpools)					
	Enter ΔLOS for carpool class 1	Δ_{CP1} = 2nd D'	R/S			
	Enter ΔLOS for carpool class 2	Δ_{CP2} = ______	R/S			Δ_{CP} = ______
	To repeat for another change in level of service, press $\boxed{D'}$ and repeat STEP 5c2. Step 5 results can also be recorded on Worksheet C-5.					
	To continue with STEP 6		R/S			
6	Store modal shares for this market segment (from Worksheet C-1)					
6a	Base drive-alone share as a fraction ** (i.e., .645, not 64.5)	S_{DA} = .139	R/S			
6b	Base carpool share as a fraction **	S_{CP} = .145	R/S			
6c	Base transit share as a fraction **	S_T = .716	R/S			
6d	Base vanpool share as a fraction **	S_{VP} = 0	R/S			
6e	Base "other" share as a fraction **	S_O = 0	R/S			
6f	Base autos per worker		R/S			A/W = .197
	If a mistake is made, press $\boxed{\text{GO TO}}\boxed{1/X}$ and begin with STEP 6a.					
6g	Base VMT		R/S			VMT_{TOT} = 332766
	If vanpool subroutine is not used, go to STEP 8	GO TO STEP 8				
7	OPTIONAL Vanpool Subroutine					
	If VP = 0 in 6d and the revised vanpool share ≠ 0, enter a "base" vanpool share on which to pivot. Defaults -- .14 for firms with ≤ 2000 employees .06 for firms with ≥ 2000 employees	S_{VP} = ______	R/S			
	If a mistake is made, press $\boxed{B'}$ and repeat STEP 7					

---

* printed but not displayed

** these five fractions must sum to 1

"D". Level-of-service changes are now entered in the exact order shown on the worksheet, including zero values, with "R/S" being pushed between each LOS entry.

Pressing "B" begins step 10 in which the predicted impacts of the ARZ are calculated and printed by the program. Each time printing ceases, R/S is pushed, through the printing of base autos per worker (step 10a). Care must be taken not to press R/S after this final value is printed. At this point, all calculations for market segment 1 are complete, and market segment 2 may be analyzed. Key "C" is pressed and the input data for market segment 2 are entered exactly as for market segment 1, beginning at step 4. After all steps for market segment 2 are completed, "E" is pressed to obtain average impacts for market segments 1 and 2 combined. Each of the results listed under step 11 of Worksheet C-4 will be printed in sequence. The results for each market segment and for work trips to the CBD as a whole as recorded on the calculator tape are shown below in the sequence in which they are printed.

Calculator Output for Non-Shuttle Scenario

Work Trips

DA Available[1]	DA Not Available[1]	Summary Results[2]	
0.197	0.0672	14538.54425	29
332766.096	24917.76	232616.708	30
.1377108186	0.	19017.60997	31
14538.54425	0.	121712.7038	32
232616.708	0.	95191.84578	33
.1436551705	.1661921319	0.	34
15166.10731	3851.502658	0.	35
97063.08681	24649.61701	357683.856	36
.7186340109	.9339078681	354329.4119	37
75868.34843	19323.49734	-3354.444142	38
0.	0.	-.9378237473	39
0.	0.		
0.	0.		
0.	0.		
329679.7948	24649.61701		
.1951728868	.0664758528		

---

[1] These values correspond to step 10 of Worksheet C-4.
[2] These values correspond to step 11 of Worksheet C-4.

WORKSHEET C-4
(continued)

(3MODE(VAN)-AGG-2(B)/790110/ESE)

USER INSTRUCTIONS

STEP	PROCEDURE	ENTER	PRESS			DISPLAY
8	Enter changes in level of service from Worksheet C-2)		D			
	If there are NO changes in level of service, Press $\boxed{\text{B}}$ and go to STEP 10; otherwise,		B			
	Drive Alone changes:					
8a	ΔIVTT_{DA}	Δ = .314	R/S			
8b	ΔOVTT_{DA}	Δ = -.084	R/S			
8c	ΔOPTC_{DA}	Δ = 0	R/S			
8d	$\Delta 4_{DA}$ **	Δ = 0	R/S			
8e	$\Delta 5_{DA}$ **	Δ = 0	R/S			
	If there are no additional changes in LOS, press $\boxed{\text{B}}$ and go to STEP 10		B			
	Carpool changes from Step 5 or Worksheet C-5 if optional STEP 5 was used:					
8f	ΔIVTT_{CP}	Δ = -.314	R/S			
8g	ΔOVTT_{CP}	Δ = -.084	R/S			
8h	ΔOPTC_{CP}	Δ = 0	R/S			
8i	$\Delta \text{INCENT}_{CP}$ *	Δ = 0	R/S			
8j	$\Delta 5_{CP}$ **	Δ = 0	R/S			
	If there are no additional changes in LOS, press $\boxed{\text{B}}$ and go to STEP 10		B			
	Transit changes:					
8k	ΔIVTT_{T}	Δ = 0	R/S			
8l	ΔOVTT_{T}	Δ = -.536	R/S			
8m	ΔOPTC_{T}	Δ = 0	R/S			
8n	$\Delta 4_{T}$ **	Δ = 0	R/S			
8o	$\Delta 5_{T}$ **	Δ = 0	R/S			
	If a mistake is made, press $\boxed{\text{GO TO}}$ $\boxed{\text{1/X}}$ and begin at STEP 6a					
	If the vanpool share in 6d = 0 and STEP 7 was not used, GO TO STEP 10	GO TO STEP	10			
9	OPTIONAL: Enter vanpool change in LOS (from Worksheet C-2)					
9a	ΔIVTT_{VP}	Δ = ______	R/S			
9b	ΔOVTT_{VP}	Δ = ______	R/S			
9c	ΔOPTC_{VP}	Δ = ______	R/S			
9d	$\Delta \text{INCENT}_{VP}$ ***	Δ = ______	R/S			
9e	$\Delta 5_{VP}$ **	Δ = ______	R/S			

* This must equal 0 or 1 unless the carpool subroutine is used, in which case it must be between 0 and 1 inclusive.

** If default coefficients are used, these Δ's must equal 0.

*** 9d must equal zero if STEP 7 was used.

WORKSHEET C-4
(continued)
(3MODE(VAN)-AGG-2(B)/790110/ESE)

USER INSTRUCTIONS

STEP	PROCEDURE	ENTER	PRESS			DISPLAY
10	Market segment results		B			
10a	New DA share *					S'_{DA} = .138
10b	New DA volume					VOL'_{DA}= 14532
10c	New DA VMT		R/S			VMT'_{DA}= 232519
10d	New CP share *		R/S			S'_{CP} = .144
10e	New CP volume					VOL'_{CP}= 15158
10f	New CP VMT		R/S			VMT'_{CP}= 97010
10g	New T share *		R/S			S'_{T} = .719
10h	New T volume					VOL'_{T} = 75884
10i	New VP share *		R/S			S'_{VP} = 0
10j	New VP volume					VOL'_{VP}= 0
10k	New VP VMT		R/S			VMT'_{VP}= 0
10l	New Other share *		R/S			S'_{O} = 0
10m	New VMT for this market segment					VMT'_{TOT}= 329499
10n	New Autos per worker * These results can also be recorded on Worksheet C-6		R/S			A/W' = .195
11	To analyze another market segment and have the results aggregated with previously analyzed market segments, press [C] and GO TO STEP 4	GO TO STEP 4	C			
	To print** aggregated results of all previous market segments, press [E]		E			
						$\Sigma VOL'_{DA}$=
						$\Sigma VMT'_{DA}$=
						$\Sigma VOL'_{CP}$=
						$\Sigma VMT'_{CP}$=
						$\Sigma VOL'_{T}$ =
						$\Sigma VOL'_{VP}$=
						$\Sigma VMT'_{VP}$=
						ΣVMT_{TOT}=
						$\Sigma VMT'_{TOT}$=
	These results can also be recorded on Worksheet C-6					$\Delta\Sigma VMT_{TOT}$=
	To analyze a new policy (no aggregation with previous market segments), press [A] and GO TO STEP 2. (Since this sets memories to zero, data from previously tested policies must be copied before A is pressed, and user-supplied coefficients, if any, must be re-entered in STEP 3.		A			$\%\Delta\Sigma VMT_{TOT}$=

* Printed but not displayed

**See Comments (Section 4) for retrieving data without a printer.

Worksheet C-4 can be used as a guide for transforming the calculator output to Worksheet C-6.

Non-Work Trips

The procedure for executing the calculator program for non-work trips is somewhat different from that for work trips, because of the use of user-supplied coefficients for the mode choice model.

The program is initialized by pressing "A" and step 3 is executed immediately to enter the user-supplied coefficients. The coefficients to be used in this analysis were derived from a joint choice model of shopping trip frequency, destination, and mode choice developed using 1968 Washington, D.C. data.[1] They reflect the different choices available to non-work travellers, and the different responses they make to changes in the transportation system compared to work travellers. Using these coefficients, both the choice of mode of ARZ bound travellers and the total number of ARZ trips will be estimated. The coefficients are:

- IVTT - 0.0582
- OVTT/DIST - 0.459

These must be entered for the drive alone mode[2] (Steps 3a and 3b) and the transit mode (Steps 3k and 3l). Only these modes need be considered, since the model only predicts auto and transit mode choices.

---

[1] Adler, T. J., and M. E. Ben-Akiva, "Joint Choice Model of Frequency, Destination and Mode Choice for Shopping Trips." Transportation Research Record 569, 1975

[2] Note that "drive alone" means all auto trips for the non-work analysis.

WORKSHEET C-4 PROGRAM STEPS

639.39
(3MODE(VAN)-AGG-2(B)/7900110/ESE)

ARZ, Non-Shuttle:

NON-WORK TRIPS
(DA AVAILABLE)

USER INSTRUCTIONS

STEP	PROCEDURE	ENTER	PRESS			DISPLAY
1	Read card(s) - partitioning is 639.39					
2	Initialize Storage Registers and store -					
	default Coefficients		A			.29
	If default coefficients are used, skip					
	to STEP 4	USE OPTIONAL	STEP 3)			
3	OPTIONAL - Enter user-supplied coefficients					
3a	coefficient of IVTT-DA mode	θ_{1DA} = -.582	STO	00		
3b	coefficient of OVTT/DIST-DA mode	θ_{2DA} = -.549	STO	01		
3c	coefficient of OPTC/Y-DA mode	θ_{3DA} = ___	STO	02		
3d	coefficient 4-DA mode	θ_{4DA} = ___	STO	03		
3e	coefficient 5-DA mode	θ_{5DA} = ___	STO	04		
3f	coefficient of IVTT-SR mode	θ_{1SR} = -.582	STO	05		
3g	coefficient of OVTT/DIST-SR mode	θ_{2SR} = -.549	STO	06		
3h	coefficient of OPTC/Y-SR mode	θ_{3SR} = ___	STO	07		
3i	coefficient of incentives-SR mode	θ_{4SR} = ___	STO	08		
3j	coefficient 5-SR mode	θ_{5SR} = ___	STO	09		
3k	coefficient of IVTT-T mode	θ_{1T} = ___	STO	10		
3l	coefficient of OVTT/DIST-T mode	θ_{2T} = ___	STO	11		
3m	coefficient of OPTC/Y-T mode	θ_{3T} = ___	STO	12		
3n	coefficient 4-T mode	θ_{4T} = ___	STO	13		
3o	coefficient 5-T mode	θ_{5T} = ___	STO	14		
	IF A MISTAKE IS MADE, BEGIN AGAIN AT STEP 3a					
4	Enter market segment data (from worksheet C-1)					
4a	round trip distance in miles ≠ 0	DIST = 16	R/S			
4b	household average annual income in $ ≠ 0	Y = 1	R/S			
	enter "1" if income is not needed for this					
	segment.					
4c	Average carpool occupancy ≠ 0	OCC_{CP} = 2.5	R/S			
	Default = 2.5					
4d	Market segment population	POP = 3,096,780	R/S			

WORKSHEET C-4
(continued)
(3MODE(VAN)-AGG-2(B)/790110/ESE)

USER INSTRUCTIONS

STEP	PROCEDURE	ENTER	PRESS			DISPLAY
4e	Average vanpool occupancy ≠ 0 default -- 10	OCC_{VP} = 1.0	R/S			
4f	Vanpool circuity factor ≠ 0 default -- 1.5	CIRC = 1.5	R/S			
	If a mistake is made, press $\boxed{C}$ and begin with STEP 4a					
	If carpool subroutine is not used, go to STEP 6	GO TO STEP 6				
5	OPTIONAL - Carpool Subroutine (data from worksheet C-3)		2nd	C'		38
5a	Enter average occupancies of two classes of carpools:					
	1. Average occupancy carpool class 1	OCC_{CP1}= ___	R/S			
	2. Average occupancy carpool class 2	OCC_{CP2}= ___	R/S			
5b	Enter level of service and mode share data					
	1. ΔIVTT - carpool class 1	Δ = ______	R/S			
	2. ΔOVTT - carpool class 1	Δ = ______	R/S			
	3. ΔOPTC - carpool class 1	Δ = ______	R/S			
	4. ΔINCENT - carpool class 1 (0/1)	Δ = ______	R/S			
	5. Δ_5 - carpool class 1**	Δ = ______	R/S			
	6. carpool class 1 share as a fraction of all carpools *	S_{CP1}= ______	R/S	2nd	E'	
	If a mistake is made, press $\boxed{C'}$ and begin with STEP 5a					
	7. ΔIVTT- carpool class 2	Δ = ______	R/S			
	8. ΔOVTT - carpool class 2	Δ = ______	R/S			
	9. ΔOPTC- carpool class 2	Δ = ______	R/S			
	10. Δ INCENT - carpool class 2 (0/1)	Δ = ______	R/S			
	11. Δ_5 - carpool class 2**	Δ = ______	R/S			
	12. carpool class 2 share as a fraction of all carpools*	S_{CP2}= ______	R/S			
	If a mistake is made, press $\boxed{C'}$ and begin with STEP 5a					

* These two values should sum to 1.0

** If default coefficients are used, these Δ's must equal zero.

After entering the user supplied model coefficients, the calculator program is executed in a manner similar to that for work trips, with changes in the base data, base mode shares, and level of service changes as noted on Worksheet C-2. Market segment 3 is analyzed first, with the market segment 4 analysis being initialized at the completion of market segment 3's calculations by pressing "C" as in the work trip analysis. At this point Step 4 is executed for market segment 4 (the coefficients of the mode choice model need not be entered a second time). The worksheets corresponding to the non-work analysis of the non-shuttle alternative appear below, along with the resulting calculator output.

CALCULATOR OUTPUT FOR NON-WORK TRIPS

DA Available[1]	DA Not Available[1]	Summary Results[2]	
0.025	0.	77107.13537	29
1238712.	0.	1233714.166	30
.0248991324	0.	0.	31
77107.13537	0.	0.	32
1233714.166	0.	106517.6702	33
0.	0.	0.	34
0.	0.	0.	35
0.	0.	1238712.	36
.0252650738	.0507288846	1233714.166	37
78240.37535	28277.29484	-4997.834136	38
0.	0.	-.4034702284	39
0.	0.		
0.	0.		
.9498357937	.9492711154		
1233714.166	0.		
.0248991324	0.		

---

[1] These values correspond to step 10 of Worksheet C-4.
[2] These values correspond to step 11 of Worksheet C-4.

WORKSHEET C-4

(continued)

(3MODE(VAN)-AGG-2(B)/790110/ESE)

USER INSTRUCTIONS

STEP	PROCEDURE	ENTER	PRESS	DISPLAY
5c	carpool subroutine results:			
	1. New average occupancy for all carpools		R/S	$^{*}OCC_{CP}$ =
	2. New carpool change in level of service (for all carpools)			
	Enter ΔLOS for carpool class 1	Δ_{CP1} = 2nd D'	R/S	
	Enter ΔLOS for carpool class 2	Δ_{CP2} =	R/S	Δ_{CP} =
	To repeat for another change in level of service, press D' and repeat STEP 5c2. Step 5 results can also be recorded on Worksheet C-5.			
	To continue with STEP 6		R/S	
6	Store modal shares for this market segment (from Worksheet C-1)			
6a	Base drive-alone share as a fraction ** (i.e., .645, not 64.5)	S_{DA} = .025	R/S	
6b	Base carpool share as a fraction **	S_{CP} = 0	R/S	
6c	Base transit share as a fraction **	S_T = .025	R/S	
6d	Base vanpool share as a fraction **	S_{VP} = 0	R/S	
6e	Base "other" share as a fraction **	S_O = .95	R/S	
6f	Base autos per worker		R/S	A/W = .025
	If a mistake is made, press GO TO 1/X and begin with STEP 6a.			
6g	Base VMT		R/S	VMT_{TOT} = 123871
	If vanpool subroutine is not used, go to STEP 8	GO TO STEP 8		
7	OPTIONAL Vanpool Subroutine			
	If VP = 0 in 6d and the revised vanpool share ≠ 0, enter a "base" vanpool share on which to pivot. Defaults -- .14 for firms with ≤ 2000 employees .06 for firms with ≥ 2000 employees	S_{VP} =	R/S	
	If a mistake is made, press B' and repeat STEP 7			

---

* printed but not displayed

** these five fractions must sum to 1

WORKSHEET C-4
(continued)

(3MODE(VAN)-AGG-2(B)/790110/ESE)

USER INSTRUCTIONS

STEP	PROCEDURE	ENTER	PRESS			DISPLAY
8	Enter changes in level of service from Worksheet C-2)		D			
	If there are NO changes in level of service, Press $\boxed{B}$ and go to STEP 10; otherwise,		B			
	Drive Alone changes:					
8a	$\Delta IVTT_{DA}$	Δ = 1.258	R/S			
8b	$\Delta OVTT_{DA}$	Δ = -.506	R/S			
8c	$\Delta OPTC_{DA}$	Δ = 0	R/S			
8d	$\Delta 4_{DA}$ **	Δ = 0	R/S			
8e	$\Delta 5_{BA}$ **	Δ = 0	R/S			
	If there are no additional changes in LOS, press $\boxed{B}$ and go to STEP 10		B			
	Carpool changes from Step 5 or Worksheet C-5 if optional STEP 5 was used:					
8f	$\Delta IVTT_{CP}$	Δ = 0	R/S			
8g	$\Delta OVTT_{CP}$	Δ = 0	R/S			
8h	$\Delta OPTC_{CP}$	Δ = 0	R/S			
8i	$\Delta INCENT_{CP}$ *	Δ = 0	R/S			
8j	$\Delta 5_{CP}$ **	Δ = 0	R/S			
	If there are no additional changes in LOS, press $\boxed{B}$ and go to STEP 10		B			
	Transit changes:					
8k	$\Delta IVTT_{T}$	Δ = 0	R/S			
8l	$\Delta OVTT_{T}$	Δ = -.536	R/S			
8m	$\Delta OPTC_{T}$	Δ = 0	R/S			
8n	$\Delta 4_{T}$ **	Δ = 0	R/S			
8o	$\Delta 5_{T}$ **	Δ = 0	R/S			
	If a mistake is made, press $\boxed{\text{GO TO}}$ $\boxed{1/X}$ and begin at STEP 6a					
	If the vanpool share in 6d = 0 and STEP 7 was not used, GO TO STEP 10	GO TO STEP 10				
9	OPTIONAL: Enter vanpool change in LOS (from Worksheet C-2)					
9a	$\Delta IVTT_{VP}$	Δ = ____	R/S			
9b	$\Delta OVTT_{VP}$	Δ = ____	R/S			
9c	$\Delta OPTC_{VP}$	Δ = ____	R/S			
9d	$\Delta INCENT_{VP}$ ***	Δ = ____	R/S			
9e	$\Delta 5_{VP}$ **	Δ = ____	R/S			

* This must equal 0 or 1 unless the carpool subroutine is used, in which case it must be between 0 and 1 inclusive.

** If default coefficients are used, these Δ's must equal 0.

*** 9d must equal zero if STEP 7 was used.

WORKSHEET C-4
(continued)
(3MODE(VAN)-AGG-2(B)/790110/ESE)

USER INSTRUCTIONS

STEP	PROCEDURE	ENTER	PRESS			DISPLAY
10	Market segment results		B			
10a	New DA share *					S'_{DA} = .024
10b	New DA volume					VOL'_{DA} = 73294
10c	New DA VMT		R/S			VMT'_{DA} = 1,172,699
10d	New CP share *		R/S			S'_{CP} = 0
10e	New CP volume					VOL'_{CP} = 0
10f	New CP VMT		R/S			VMT'_{CP} = 0
10g	New T share *		R/S			S'_{T} = .025
10h	New T volume					VOL'_{T} = 78339
10i	New VP share *		R/S			S'_{VP} = 0
10j	New VP volume					VOL'_{VP} = 0
10k	New VP VMT		R/S			VMT'_{VP} = 0
10l	New Other share *		R/S			S'_{O} = .951
10m	New VMT for this market segment					VMT'_{TOT} = 1,172,698
10n	New Autos per worker * These results can also be recorded on Worksheet C-6		R/S			A/W' = .024
11	To analyze another market segment and have the results aggregated with previously analyzed market segments, press [C] and GO TO STEP 4	GO TO STEP 4	C			
	To print** aggregated results of all previous market segments, press [E]		E			$\Sigma VOL'_{DA}$ = $\Sigma VMT'_{DA}$ = $\Sigma VOL'_{CP}$ = $\Sigma VMT'_{CP}$ = $\Sigma VOL'_{T}$ = $\Sigma VOL'_{VP}$ = $\Sigma VMT'_{VP}$ = ΣVMT_{TOT} = $\Sigma VMT'_{TOT}$ = $\Delta\Sigma VMT_{TOT}$ = $\%\Delta\Sigma VMT_{TOT}$ =
	These results can also be recorded on Worksheet C-6					
	To analyze a new policy (no aggregation with previous market segments), press [A] and GO TO STEP 2. (Since this sets memories to zero, data from previously tested policies must be copied before A is pressed, and user-supplied coefficients, if any, must be re-entered in STEP 3.		A			.29

* Printed but not displayed

**See Comments (Section 4) for retrieving data without a printer.

The printed results for each market segment and the entire population are entered on Worksheet C-6, once again using Worksheet C-4 as a reference for the printed output values, and noting that the mode share for the "other" mode refers to all non-work trips made to non-CBD locations regardless of travel mode. The drive alone mode share reported by the program is the share of all non-work person-trips in the urban area made to the CBD by the auto. The transit share shown for market segments 3 and 4 has a similar meaning.

Copies of Worksheet C-6 for the non-shuttle and shuttle scenarios appear below. The change in VMT for work and non-work VMT are calculated by subtracting the "New VMT" total from the "Base VMT" total for each trip type.

Caution must be used in interpreting the VMT change estimates calculated for non-work trips. Unlike the change in work VMT, the estimate does not represent a direct measure of the areawide change in auto VMT. Work trips are fixed with respect to destination and the VMT changes shown on Worksheet C-6 are due solely to mode changes. Both the mode and destination of non-work trips may change however. The VMT change shown on Worksheet C-6 for non-work trips is the change in the VMT accounted for by auto trips to the CBD. This change in CBD-bound VMT could be caused by shifts of ARZ-bound travellers to transit from autos or shifts in the destination of non-work auto trips from the CBD to other locations in the urban area. Consequently, the areawide non-work VMT impact of the ARZ proposals can not be determined without making assumptions concerning the relative proportion of auto trips formerly made to the CBD

WORKSHEET C-6

Results by Market Segment

Policy: Downtown ARZ Without Shuttle

RESULTS BY MARKET SEGMENT

Population Subgroup	Base Autos Per Worker	Base VMT	New Drive Alone			New Carpool			New Transit		New Vanpool			New Other Share	New VMT	New Autos Per Worker
			Share	Vol	VMT	Share	Vol	VMT	Share	Vol	Share	Vol	VMT			
1. Work Trips with Drive Alone	.197	332,766	.138	14,530	232,490	.144	15,158	97,010	.719	75,885	0	0	0	0	329,500	.195
2. Work Trips without DA	.067	24,918	0	0	0	.166	3,849	24,634	.834	19,326	0	0	0	0	24,634	.066
3. Non-Work Trips with DA	.025	1,238,712	.024	75,319	1,172,699	0	0	0	.026	81,263	0	0	0	.949	1,172,699	.024
4. Non-Work Trips without DA	0	0	0	0	0	0	0	0	.053	29,776	0	0	0	.947	0	0
TOTALS Work		357,684		14,531	232,490		19,007	121,644		95,210		0	0		354,133	
TOTALS Non-Work		1,238,712		73,294	1,172,699					106,495		0	0		1,172,699	

	Change in VMT	Percent Change in VMT
Work	- 3,551	-1.0
Non-Work	-66,013	-5.3

WORKSHEET C-6

Results by Market Segment

Policy: Downtown ARZ with Shuttle

RESULTS BY MARKET SEGMENT

Population Subgroup	Base Autos Per Worker	Base VMT	New Drive Alone			New Carpool			New Transit		New Vanpool			New Other Share	New VMT	New Autos Per Worker
			Share	Vol	VMT	Share	Vol	VMT	Share	Vol	Share	Vol	VMT			
1. Work Trips with DA	.197	332,766	.138	14,539	232,616	.144	15,166	97,063	.719	75,868	0	0	0	0	329,500	.195
2. Work Trips without DA	.067	24,918	0	0	0	.166	3,852	24,650	.834	19,323	0	0	0	0	24,634	.066
3. Non-Work Trips with DA	.025	1,238,712	.025	76,935	1,233,714	0	0	0	.027	82,869	0	0	0	.948	1,233,714	.025
4. Non-Work Trips without DA	0	0	0	0	0	0	0	0	.053	29,776	0	0	0	.947	0	0
TOTALS Work		357,684		14,538	232,617		19,017	121,713		95,192		0	0		354,329	
TOTALS Non-Work		1,238,712		77,107	1,233,714		0	0		106,518		0	0		1,233,712	

	Change in VMT	Percent Change in VMT
Work	-3355	-0.9
Non-Work	-4998	-0.4

which are diverted to other destinations vs. auto trips to the CBD which are diverted to transit, but still bound for the CBD.

However, it is possible to predict the changes in auto VMT within the CBD, and the resulting reduction in CO emissions, related to the proposed auto restrictions directly from the calculator outputs, if the proportion of the total VMT which occurs in the CBD is known. Assuming that 1/16 of the average trip mileage occurs in the CBD, non-work VMT in the downtown area is reduced by 4,125 vehicle miles per day for the non-work shuttle alternative, and 312 vehicle miles per day for the shuttle option. These CBD VMT reductions may be used in the manual emissions worksheets to determine the CO emissions impact of the competing proposals.

H. Impact Assessment

Emissions, fuel consumption, and operating costs impacts can be determined for portions of the travel affected by the ARZ using the methods discussed in Chapter 4 of Volume I. The emissions impacts of the alternative ARZ plans are analyzed using separate sets of the manual emissions worksheets. To analyze both the shuttle and non-shuttle alternative, the worksheets must be executed three times; once each for the base case and each of the alternative revised cases. Only the base case and non-shuttle worksheets are discussed in detail for illustrative purposes. The calculations for the shuttle alternative are identical with the exception of differences in the VMT values used in the procedures. The forecast year of 1982 used in the VMT analysis is assumed.

Areawide emissions impacts may be determined for work trips (Market Segments 1 and 2) because the VMT impacts predicted by 3MODE(VAN)-AGG refer to areawide total changes in work VMT. However, for non-work trips to the ARZ, only the change in vehicle emissions within the downtown area may be calculated. The program predicts changes in the volume of auto travel to the downtown area, but because these changes could occur as a result of either shifts to transit by auto users or simply changes in the destination of auto shopping trips, the net areawide change in VMT can not be ascertained. The estimated change in downtown auto tripmaking and VMT may be used to determine the impact of the proposed ARZ alternatives on CO concentrations in the downtown area, which suffers from frequent violations of the CO health standards.

Worksheet VI-A is used to record the base and revised work VMT and trip lengths for market segments 1 and 2, and non-work VMT and trip lengths for market segments 3 and 4. The non-work VMT recorded on Worksheet VI-A is the portion of downtown-bound VMT within the downtown area (1/16 of the total non-work VMT recorded on Worksheet C-6). Similarly, the trip distance recorded for non-work trips is 0.5 mile, corresponding to the one-way length of each non-work trip which occurs in the downtown area. Table D.2 provides the required percentage of cold starts for work and non-work trips for Worksheet VI-B.

Worksheets VI-C and VI-D are used to calculate the base and revised emissions associated with downtown trip making. Emissions Tables D.3, D.4 and D.5 provide the required cold-start emissions factors for use in Worksheet VI-C with an ambient temperature of 50° used to enter the tables. Only the CO factor need be obtained for non-work trips since only the concentration of CO in the downtown area is of interest with respect to non-work trips. The execution of Worksheet VI-D is straightforward,

VI-A. INPUT TRAVEL DATA SUMMARY FOR EMISSIONS ESTIMATION

☒ Base Alternative
☐ Revised Alternative
Forecast Year: 1982
Policy: ARZ

Population Subgroup	Work VMT (I or IV)[1]	÷	Average Work Trip Distance (miles)(I)	=	Number of One-Way Work Trips		Non-Work VMT (I or IV)	÷	Average Non-Work Trip Distance (miles) (I)	=	Non-Work Trips
1	332,766		(III or I) 8		41,596		-		-		-
2	24,918		8		3,115		-		-		-
3	-						77,420		0.5		154,840
4	-						0		0.5		0
$\sum =$	357,684			$\sum =$	44,711	$\sum =$	77,420			$\sum =$	154,840
	TOTAL WORK VMT				TOTAL WORK TRIPS		TOTAL NON-WORK VMT				TOTAL NON-WORK TRIPS

-- TOTAL TRIPS

---

[1] Source Worksheets are indicated in parentheses where applicable. VMT and trips on worksheets I and IV in Appendix A must be multiplied by the number of households per population subgroup.

VI-A. INPUT TRAVEL DATA SUMMARY FOR EMISSIONS ESTIMATION

☐ Base Alternative
☒ Revised Alternative - Non-Shuttle
Forecast Year: 1982
Policy: ARZ

Population Subgroup	Work VMT (I or IV)[1]	÷	Average Work Trip Distance (miles)(I)	=	Number of One-Way Work Trips		Non-Work VMT (I or IV)	÷	Average Non-Work Trip Distance (miles) (I)	=	Non-Work Trips
1	329,500		(IV or I) 8		41,188		-		-		-
2	24,634		8		3,079		-		-		-
3	-		-		-		73,293		0.5		146,587
4	-		-		-		0		0.5		0
$\sum =$	354,134			$\sum =$	44,267	$\sum =$	73,293			$\sum =$	146,587
	TOTAL WORK VMT				TOTAL WORK TRIPS		TOTAL NON-WORK VMT				TOTAL NON-WORK TRIPS

TOTAL TRIPS: ☐

---

[1] Source Worksheets are indicated in parentheses where applicable. VMT and trips on worksheets I and IV in Appendix A must be multiplied by the number of households per population subgroup.

VI-B. COLD START FRACTIONS

☒ Base Alternative

☐ Revised Alternative

Policy: ARZ

Subgroup: All

Forecast Year: 1982

1. If Daily Parking Duration Data are Available:

% of Auto Trips by Catalyst-Equipped Vehicles (Table D.1)		% of Auto Trips with Parking Duration 1 hour		% of Auto Trips by Non-Catalyst Equipped Vehicles		% of Auto Trips with Parking Duration 4 hours		% of Auto Trips with Cold Starts
	X		+		X		=	

2. If Daily Parking Duration Data are not Available (Table III-2)

% of Work Trip Cold Starts (Table D.2)

90

% Non-Work Trip Cold Starts (Table D.2)

57

VI-B. COLD START FRACTIONS

☐ Base Alternative

☒ Revised Alternative

Policy: ARZ

Subgroup: All

Forecast Year: 1982

1. If Daily Parking Duration Data are Available:

% of Auto Trips by Catalyst-Equipped Vehicles (Table D.1)		% of Auto Trips with Parking Duration 1 hour		% of Auto Trips by Non-Catalyst Equipped Vehicles		% of Auto Trips with Parking Duration 4 hours		% of Auto Trips with Cold Starts
	X		+		X		=	

2. If Daily Parking Duration Data are not Available

% of Work Trip Cold Starts (Table D.2)

90

% Non-Work Trip Cold Starts (Table D.2)

57

VI-C. AUTO START-UP AND EVAPORATIVE EMISSIONS

☒ Base Alternative

☐ Revised Alternative

Policy: ARZ

Forecast Year: 1982

Temperature: 50 F

	Work Trips						Non-Work Trips			
(1) Population Subgroup	(2) % Cold Starts (VI-B)[1]	(3) Trips (IV-A)	Pollutant[2]	From Table[3]	(4) Start-Up Factors	(5) Emissions = Col. 3 X Col. 4 (grams)	(6) % Cold Starts (VI-B)	(7) Trips (VI-A)	(8) Start-Up Factors	(9) Emissions = Col. 3 X Col. 4 (grams)
1,2	90	44,711	HC(c)	D.2	12.3	549,945				
			CO(c)	D.3	199	8,896,489				
			NOx(c	D.4	3.4	153,017				
			HC(h)	D.6	6.0	268,266				
			HC(c)	D.2			57	154,840	CO 130	20,129,200
			CO(c)	D.3						
			NOx(c	D.4						
			HC(h)	D.6						
			HC(c)	D.2						
			CO(c)	D.3						
			NOx(c	D.4						
			HC(h)	D.6						

TOTALS

TOTALS $\sum$ Subgroups	Work Trip Start-Up Emissions (grams)	+	$\sum$ Subgroups	Non-Work Trip Start-Up Emissions (grams)	=	Total Start-Up Emissions (grams)
HC	818,211		HC			
CO	8,896,489		CO	20,129,200		
NOx	152,017		NOx			

---

[1] Source Worksheets are indicated in parentheses where applicable

[2] (c) indicates cold start factor

(h) indicates hot soak factor

[3] both work and non-work start-up factors obtained from the indicated tables

VI-C. AUTO START-UP AND EVAPORATIVE EMISSIONS

☐ Base Alternative

☒ Revised Alternative - Non-Shuttle

Policy: ARZ

Forecast Year: 1982

Temperature: 50 F

	Work Trips						Non-Work Trips			
(1) Population Subgroup	(2) % Cold Starts (VI-B)[1]	(3) Trips (IV-A)	Pollut-ant[2]	From Table[3]	(4) Start-Up Factors	(5) Emissions = Col. 3 X Col. 4 (grams)	(6) % Cold Starts (VI-B)	(7) Trips (VI-A)	(8) Start-Up Factors	(9) Emissions = Col. 3 X Col. 4 (grams)
1,2	90	44,188	HC(c)	D.2	12.3	543,512				
			CO(c)	D.3	199	8,793,412				
			NOx(c	D.4	3.4	150,239				
			HC(h)	D.6	6.0	265,128				
			HC(c)	D.2						
			CO(c)	D.3			57	146,587	CO 130	19,056,310
			NOx(c	D.4						
			HC(h)	D.6						
			HC(c)	D.2						
			CO(c)	D.3						
			NOx(c	D.4						
			HC(h)	D.6						

TOTALS

TOTALS $\sum$ Subgroups	Work Trip Start-Up Emissions (grams)	+	$\sum$ Subgroups	Non-Work Trip Start-Up Emissions (grams)	=	Total Start-Up Emissions (grams)
HC	808,640		HC			
CO	8,793,412		CO	19,056,310		
NOx	150,239		NOx			

---

[1] Source Worksheets are indicated in parentheses where applicable

[2] (c) indicates cold start factor

(h) indicates hot soak factor

[3] both work and non-work start-up factors obtained from the indicated tables

VI-D. AUTO TRAVEL EMISSIONS

☒ Base Alternative

☐ Revised Alternative

Policy: ARZ

Forecast Year: 1982

	Work Trips				Non-Work Trips			
(1) Population Subgroup	(2) Average Speed	(3) VMT (VI-A)[1]	(4) Auto Travel Factors (Table D.7)	(5) Emissions = Col. 3 X Col. 4 (grams)	(6) Average Speed	(7) VMT (VI-A)	(8) Auto Travel Factors (Table D.7)	(9) Emissions = Col. 7 X Col. 8 (grams)
1,2	25	357,684	HC 1.6	572,294			HC	
			CO 24.3	8,691,721			CO	
			NOx 2.1	751,136			NOx	
3,4	-	-	HC		15	77,420	HC	
			CO				CO 37.0	2,864,540
			NOx				NOx	
			HC				HC	
			CO				CO	
			NOx				NOx	
			HC				HC	
			CO				CO	
			NOx				NOx	
			HC				HC	
			CO				CO	
			NOx				NOx	
			HC				HC	
			CO				CO	
			NOx				NOx	

TOTALS $\sum$ Subgroups

	Work Trip Travel Emissions (grams)	+ $\sum$ Subgroups	Non-Work Trip Travel Emissions (grams)	=	Total VMT Travel Emissions (grams)
HC	572,294	HC			
CO	8,691,721	CO	2,864,540		
NOx	751,136	NOx			

---

[1] Source Worksheets are indicated in parentheses where applicable

VI-D. AUTO TRAVEL EMISSIONS

☐ Base Alternative

☒ Revised Alternative

Policy: HOV Lane - Non-Shuttle

Forecast Year: 1982

	Work Trips				Non-Work Trips			
(1) Population Subgroup	(2) Average Speed	(3) VMT (VI-A)[1]	(4) Auto Travel Factors (Table D.7)	(5) Emissions = Col. 3 X Col. 4 (grams)	(6) Average Speed	(7) VMT (VI-A)	(8) Auto Travel Factors (Table D.7)	(9) Emissions = Col. 7 X Col. 8 (grams)
1,2	25	354,134	HC 1.6	566,614	30	-	HC	
			CO 24.3	8,605,456			CO	
			NOx 2.1	743,681			NOx	
3,4	-	-	HC		15	73,293	HC	
			CO				CO 37.0	2,711,841
			NOx				NOx	
			HC				HC	
			CO				CO	
			NOx				NOx	
			HC				HC	
			CO				CO	
			NOx				NOx	
			HC				HC	
			CO				CO	
			NOx				NOx	
			HC				HC	
			CO				CO	
			NOx				NOx	

TOTALS

	$\sum$ Subgroups: Work Trip Travel Emissions (grams)	+ $\sum$ Subgroups: Non-Work Trip Travel Emissions (grams)	= Total VMT Travel Emissions (grams)
HC	566,614		-
CO	8,605,456	2,711,841	-
NOx	743,681		-

---

[1] Source Worksheets are indicated in parentheses where applicable

again considering only CO emissions in the downtown area for non-work trips. An average travel speed of 25 mph is assumed for work trips. For the downtown portion of non-work trips, an average speed of 15 mph is used, based on observations of traffic flow in the CBD. The predicted base and revised emissions for the ARZ proposal are summarized in Worksheet VI-E, which is also used to calculate the net and percentage change in emissions for the revised alternative.

For work trips, the emissions figures for Worksheet VI-E are taken directly from the previous worksheets. However, for non-work trips, start-up emissions calculated in Worksheet VI-C represent the total round trip emissions while only one-half of the total one-way non-work trips begin in the downtown area. Therefore, to obtain the start up CO emissions in the downtown area alone, the total emissions for the base and revised cases must be divided by two.

Auto fuel consumption and operating cost estimates of CBD-bound vehicle trips for work can be estimated using the manual method presented in Section 4.2 and Appendix E of Volume I. The Base, Shuttle, and Non-Shuttle input values are shown in Table II-1, along with the resulting estimated fuel consumed and operating costs. The inputs reflect illustrative projections of average vehicle weights, automotive technology, gasoline costs, and auto maintenance costs for the analysis year, 1982.

I. Interpretation of Results

Care must be taken in interpreting the predicted impacts of the ARZ measures. The changes in work trip emissions shown on Worksheet VI-E reflect the net change in areawide emissions associated with the auto re-

VI-E. SUMMARY OF CHANGES IN EMISSIONS

Revised Alternative

Policy: ARZ, No Shuttle

Forecast Year: 1982

(1) Population Subgroup		Base Emissions (2) Trip-Related (VI-C)[1]	(3) Travel (VI-D)	(4) Total (Col.2 + Col.3)	Revised Emissions (5) Trip-Related (VI-C)	(6) Travel (VI-D)	(7) Total (Col.5+Col.6)	(8) Change in Total Emissions (Col.4-Col.7)	(9) Percent Change in Emissions (Col.8/Col.4) x 100
1,2	HC	818,211	572,294	1,390,505	808,640	566,614	1,375,254	- 15,251	-1.1
	CO	8,897,489	8,691,721	17,589,210	8,793,412	8,605,456	17,398,868	-190,342	-1.1
	NOx	152,017	751,136	903,153	150,239	743,681	893,920	- 9,233	-1.0
3,4 (ARZ only)	HC								
	CO	10,064,600	2,864,540	12,929,140	9,528,180	2,711,841	12,250,021	-689,119	-5.3
	NOx								
	HC								
	CO								
	NOx								
	HC								
	CO								
	NO_x								

TOTALS

∑ Sub-groups

	Total Base Emissions (grams)
HC	1,390,505
CO	17,589,210
NOx	903,153

∑ Sub-groups

	Total Change in Emissions (grams)	Percent Change, Total Emissions
HC	-15,251	-1.1
CO	-190,342	-1.1
NOx	- 9,233	-1.0

---

[1] Source Worksheets are indicated in parentheses where applicable

VI-E. SUMMARY OF CHANGES IN EMISSIONS

Revised Alternative

Policy: ARZ, With Shuttle

Forecast Year: 1982

(1) Population Subgroup		Base Emissions (2) Trip-Related (VI-C)[1]	(3) Travel (VI-D)	(4) Total (Col.2 + Col.3)	Revised Emissions (5) Trip-Related (VI-C)	(6) Travel (VI-D)	(7) Total (Col.5+Col. 6)	(8) Change in Total Emissions (Col. 4-Col. 7)	(9) Percent Change in Emissions (Col. 8/Col.4) x 100
1,2	HC	818,211	572,294	1,390,505	808,640	566,614	1,375,254	- 15,251	-1.1
	CO	8,897,489	8,691.721	17,589,210	8,793,412	8,605,456	17,398,868	-190,342	-1.1
	NOx	152,017	751,136	903,153	150,239	743,681	893,920	- 9,233	-1.0
3,4 (ARZ only)	HC								
	CO	10,064,600	2,864,540	12,929,140	10,023,910	2,852,959	12,876,869	- 52,271	-0.4
	NOx								
	HC								
	CO								
	NOx								
	HC								
	CO								
	NO_x								

TOTALS

$\sum$ Sub-groups	Total Base Emissions (grams)
HC	1,390,505
CO	17,589,210
NOx	903,153

$\sum$ Sub-groups	Total Change in Emissions (grams)	Percent Change, Total Emissions
HC	-15,251	-1.1
CO	-190,342	-1.1
NOx	- 9,233	-1.0

---

[1] Source Worksheets are indicated in parentheses where applicable

TABLE II-1

Auto Fuel Consumption and Operating Cost Impacts for Work Trips

	Alternative			
Variable	Base	Shuttle	Non-Shuttle	Source
Inputs				
WT	3.37	3.37	3.37	auto industry projections
RFC	1.0	1.0	1.0	auto industry projections
TEMP	7	7	7	local weather data
GCOST	1.50	1.50	1.50	Department of Energy projections
RMTCOST	0.0595	0.0595	0.0595	local economic projections
TIME	19.2	19.2	19.2	DIST x 60/SPEED; SPEED from Worksheet VI-D
DIST	8	8	8	Worksheet VI-A
TPHH*HHS	44,711	44,260	44,267	Worksheet VI-A
Estimated Values				
FUEL (gal/day)	24,428	24,182	24,185	Procedure presented in Volume I, Appendix E
OCOST ($/day)	$57,924	$57,340	$57,349	

strictions. The percentage changes, however, refer only to downtown-bound travel. To develop an estimate of the areawide percentage change in vehicle emissions, the total work trip vehicle emissions in the region would have to be calculated and compared to the predicted emissions changes associated with the ARZ proposals.

Also, the predicted reduction in downtown area CO estimates for non-work trips should not be interpreted as a net reduction of CO emissions throughout the urban area. This reduction is due in part to an overall change in non-work auto use and in part to a shift in the destination of non-work auto trips. Thus, a portion of the decrease in CO emissions in downtown is accompanied by a similar increase in CO emissions in other parts of the urban area. The information available from the analysis is not sufficient to determine to what extent CO emissions in other areas would increase if auto restriction is undertaken downtown.

The fuel consumption and operating cost impacts are also limited to a portion of total urban travel: they reflect only changes in CBD-bound work travel. Because no changes are predicted in average work trip length or in average work trip speed due to the implementation of the ARZ, the computed changes in fuel consumption and operating costs vary directly with the changes in the number of auto work trips.

From the results summarized in Worksheets C-6 and VI-E, and in Table II-1, it is apparent that the work trip VMT and emissions impacts of both the shuttle and non-shuttle alternatives are marginal and that the availability of the proposed shuttle service will have essentially no impact on the travel behavior of downtown workers. More significant impacts on vehicle emissions and a greater shuttle service impact on travel behavior are predicted for non-work trips, however. A 5.3 percent decrease in auto VMT in the downtown area and an overall reduction in total trip-making to the downtown area of 1.6 percent[1] is predicted for the non-shuttle alternative with a corresponding 5.3 percent reduction in CO emissions. Adding the shuttle to the ARZ proposal makes the downtown area much more attractive as a non-work destination, relative to the non-shuttle alternative and leads to an overall increase in non-work trip making to the area. Slightly fewer downtown-bound non-work trips are predicted for the ARZ with shuttle than for the base case, and the impact of the ARZ with shuttle on CO concentrations in the downtown area would be negligible.

In evaluating the relative merits of the shuttle and non-shuttle alternatives, the importance of the viability of downtown as a major shopping district would have to be weighed against the desire to reduce CO concentrations in the area. The non-shuttle alternative is predicted to lead to a decrease in total non-work travel to the area, while the with-shuttle option will lead to little or no change in CO emissions downtown. Another consideration in using and interpreting the results of this analysis is that changes in the attractiveness of the ARZ caused by factors other than changes in transportation level of service have not been included in the analysis. If the area is made more attractive as a shopping destination through the addition of new shopping space or beautification measures, somewhat different impacts with respect to total trip making to the area than those predicted by this simple analysis would be expected. However, the relative impact of the shuttle and non-shuttle alternatives on non-work travel to the ARZ is accurately reflected by the results of this analysis.

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[1] Calculated using the base and revised "other" mode shares on Worksheets C-1 and C-6 to determine the number of trips bound for other parts of the urban area.

CASE STUDY III

BUS PRIORITY STRATEGIES FOR A RADIAL URBAN CORRIDOR

CASE STUDY III: BUS PRIORITY STRATEGIES FOR A RADIAL URBAN CORRIDOR[1]

A. Problem Presentation

A one mile wide radial travel corridor in a major urban area, served by a single express bus route, has been identified as a candidate for bus priority treatments. High peak period auto volumes in the corridor are contributing to the metropolitan area's air quality problems, which include violations of the ozone and CO health standards. Operations on the bus route are adversely affected by conflicts with autos in the traffic stream and the contribution of buses idling in traffic to the area's air quality problems is an increasing concern, particularly for the residents of the corridor.

A four-lane major arterial in the corridor serves work trips between the corridor's residential areas and the major employment centers in the central city. The section of the arterial under study is 5.3 miles in length, stretching from the residential sections to a major transit transfer facility where the bus route serving the corridor terminates. (See Figure III-1). Downtown-bound transit passengers transfer to a rapid transit line at the transfer facility, while auto users continue into the central city by a number of routes.

---

[1] This Case Study was originally developed as part of the Responsive Analysis Methods Project conducted by the Center for Transportation Studies, Massachusetts Institute of Technology. It has been adapted from material in: Responsive Transportation Analysis: Pocket Calculator Methods, Volume II, Examples of Transportation Analyses, by M.L. Manheim, P. Furth, and I. Salomon, MIT, August, 1978.

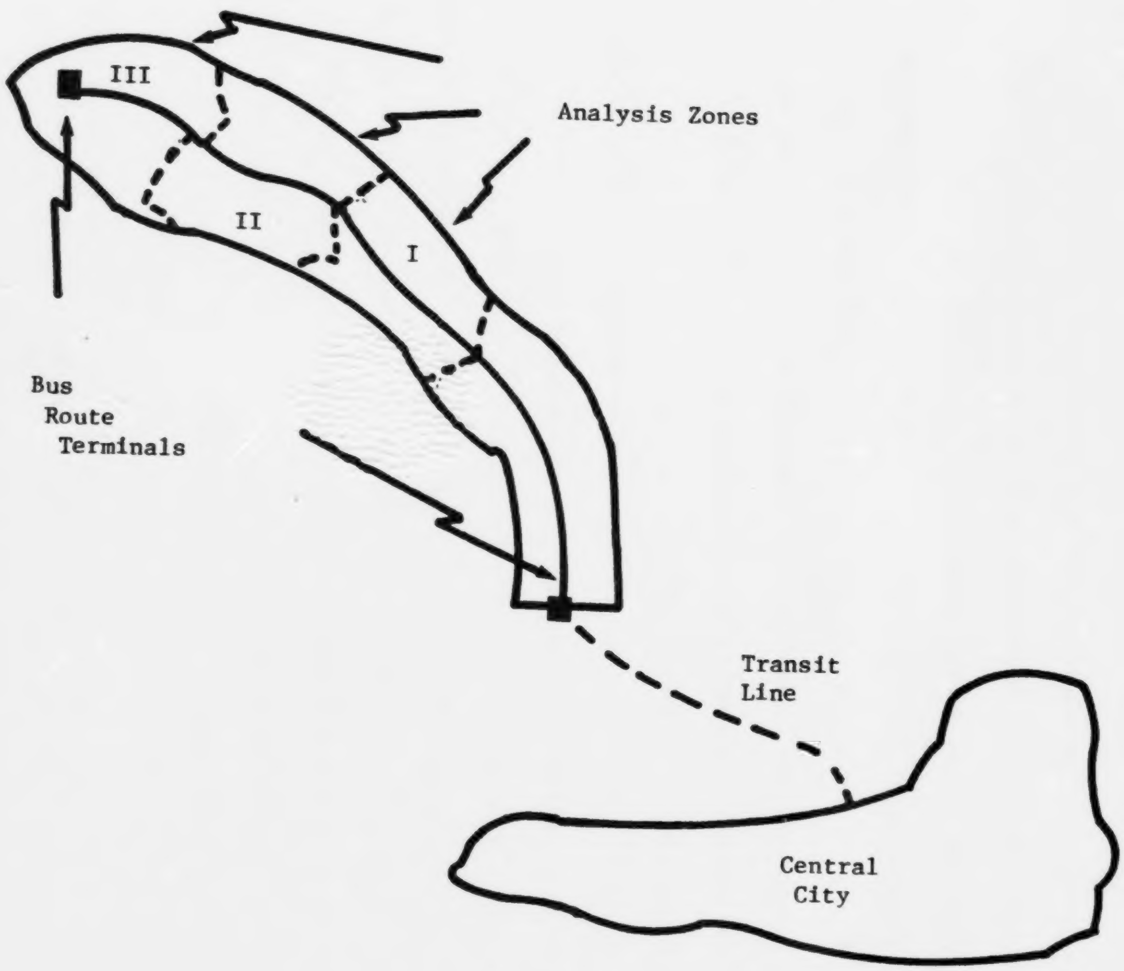


FIGURE III-1

Study Corrdior with Residential Analysis Zones

B. Proposed Transportation Measures

In order to encourage increased transit usage by improving the service on the corridor's bus route, two bus priority measures have been proposed for implementation by 1982:

1) Preferential Signal Control for buses at intersections;

2) Preferential Signal Control and Preferential Lanes for buses.

These measures are also expected to reduce bus pollutant emissions and lower the cost of providing bus service in the corridor. Because the volume of traffic is below the capacity of the arterial, no major impact on auto level of service is expected for either measure. Reduced in-vehicle travel time for bus trips is the only transportation level-of-service change anticipated.

C. Selection of Analysis Technique

A detailed evaluation of the proposed measures' impacts on mobile source emissions and transit operating costs is required to support a decision on implementation. Both auto and bus emissions are of interest, as well as bus fuel consumption (a measure of the operating cost impact of the measures).

However, the budget and data available for the analysis are limited, and the metropolitan area's computer-based model system is not well suited to a detailed analysis of specific transit measures such as the two proposed for the study corridor. Programmable calculator methods provide the accuracy required for the analysis, but do not require extensive data or costly computerized calculations to support accurate predictions.

Calculator program 3MODE(VAN)-AGG (2.2.3)[1] is selected for the analysis of the mode choice impact of the proposed measures because of its efficiency in using available data and its accuracy in representing behavioral decisions. Since bus fuel consumption and emissions are of critical interest, programs BUS (3.2.1), BUSPOL and ENERGY (4.3) are also selected. Finally, auto emissions are predicted using the auto emissions worksheets (4.1).

The base data available for the corridor is limited to 1970 census tract and block data. No mode split information is available and the analysis budget is not large enough to allow traffic or transit counts to be made. In order to develop base case data, calculator programs HHGEN (2.2.1) and a two-mode calculator mode choice program (2MODE-AGG) are selected to develop a sample of residential households for forecasting use and to estimate existing mode splits based on the current levels of service offered by the auto and transit modes in the corridor. Using this set of programmable calculator methods, an estimate of the fuel consumption and emissions impact of the proposed priority measures can be made using only census and level-of-service data.

D. Overview of the Analysis

The analysis of the effects of changes in operating policies on bus ridership and environmental factors consists of three major tasks:

- Collection, estimation, and preparation of data
- Equilibration of bus ridership and bus performance
- Calculation of the environmental impacts of the equilibrium bus ridership

---

[1] The section numbers following specified analysis methods refer to the location of their description in Volume I. In addition, master copies of worksheets are provided in Appendices C and D of Volume I.

The three tasks consist of the nine steps shown in the analysis flow diagram of Figure III-2. The six calculator programs used in the analysis are also shown.[1]

Task 1. Collection, Estimation, and Preparation of Data

This task includes Steps 1 to 4. The data items needed to exercise these steps include census data for the analysis corridor, approximate existing travel times and costs for bus and auto trips, information on the work trip destination for residents of the corridor, and detailed data on the bus route operating in the corridor.

Census tract and block data from 1970; specifically total population, population in group quarters, type of housing, auto ownership, income and housing tenure; is required for Step 1. The output from program HHGEN in Step 1 is combined with work trip destination data developed in Step 2 and level of service estimates for auto and transit from Steps 3 and 4 for input to Task 2. Step 4 also includes an in-depth analysis of the corridor bus route including traffic signal settings, line segment lengths (distances between stops and intersections), and the location of bus stops. This information is used by program BUS in Task 2.

Task 2. Equilibration

Because the bus route simulation program is ultimately used to test the effects of different operating policies on route performance, it is important that, in base case conditions, the predictions of ridership and performance are in equilibrium. Ridership and performance on a bus route are functions of each other:

---

[1] Detailed descriptions of the programs may be found in M.L. Manheim, P. Furth, and I. Salomon, Responsive Transportation Analysis Pocket Calculator Methods, Volume 3; Program Library, Center for Transportation Studies, Massachusetts Institute of Technology, October, 1978.

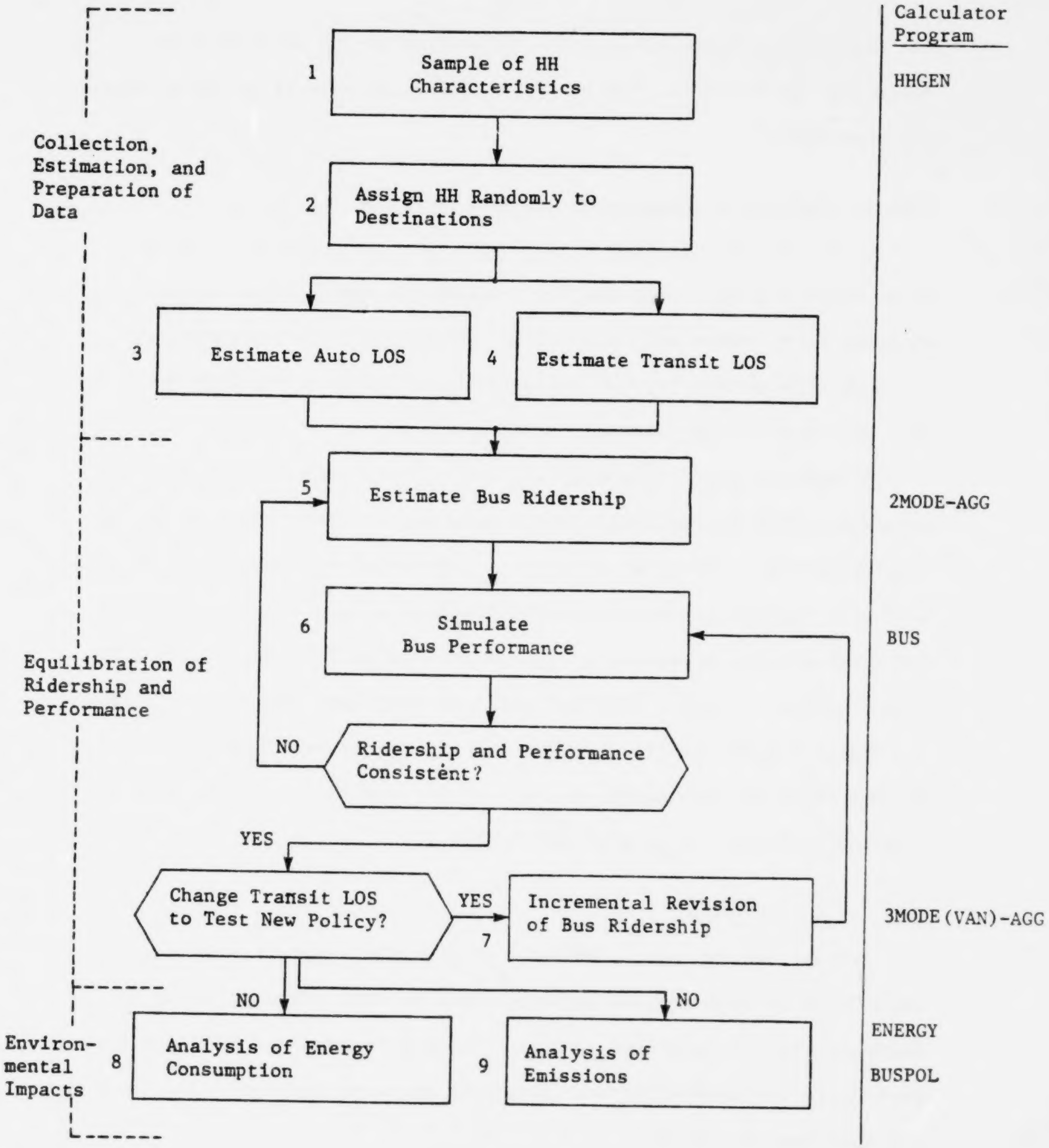

Calculator Program
1
Sample of HH Characteristics
HHGEN
Collection, Estimation, and Preparation of Data
2
Assign HH Randomly to Destinations
3
Estimate Auto LOS
4
Estimate Transit LOS
5
Estimate Bus Ridership
2MODE-AGG
6
Simulate Bus Performance
BUS
Equilibration of Ridership and Performance
NO
Ridership and Performance Consistent?
YES
Change Transit LOS to Test New Policy?
YES
7
Incremental Revision of Bus Ridership
3MODE(VAN)-AGG
NO
NO
ENERGY
Environmental Impacts
8
Analysis of Energy Consumption
9
Analysis of Emissions
BUSPOL

FIGURE III-2

Integrated Analysis Steps and Programs

$$\text{Ridership} = D\,(\text{Performance}) \qquad (1)$$

$$\text{Performance} = S\,(\text{Ridership}) \qquad (2)$$

Equation (1) is the demand function, in which increases in transit ridership demands are predicted as transit preformance improves. Equation (2) is the supply function, in which decreases in transit performance are predicted, due to congestion and longer boarding times, as transit ridership increases. Equilibrium occurs when the values of ridership and performance satisfy both Equations (1) and (2). Such values are termed consistent, or equilibrium values. In this case study, equilibrium values are found by iteratively applying in turn the separate programmable calculator routines which represent Equations (1) and (2). This is done in Steps 5-7, using either program 2MODE-AGG or program 3MODE(VAN)-AGG for Equation (1), and program BUS for Equation (2).

Each time one of these programs is used, its input data are taken from the most recent prediction of the other program. Iteration stops when the input and output values of the ridership and performance variables no longer change. When transit service is changed by the proposed transportation policies, equilibration is again necessary so that bus ridership and performance reflect the influences that each has on the other.

Task 3. Environmental Impacts

When mode shares have been determined with ridership/performance equilibration, bus energy consumption and emissions can be forecast based on bus vehicle-miles travelled, travel speed in the corridor, and assumptions about average fleet characteristics. Two programs, ENERGY and BUSPOL, are used to determine bus environmental impacts in Step 8 and 9, respectively. In Step 9, auto emissions are also estimated using the auto emissions worksheets.

E. Defining the Scope of the Analysis

Because the bus route serving the corridor in the peak period carries almost exclusively downtown-bound passengers, only downtown work trips are considered in the analysis. The route operates as a local service only in the residential area shown in Figure III-1. Outside this area, inboud stops are made only to discharge passengers. Therefore, the analysis will focus on workers in the residential section of the corridor who are bound for the central city during the morning peak hour. The residential area is partitioned into three analysis zones, with the divisions between zones roughly corresponding to census tract boundaries. Only residents within one-half mile of the arterial on which the bus route operates are considered because the number of bus passengers walking over one-half mile to the route is assumed to be negligible.

A sample of 18 households, six from each analysis zone, are generated for forecasting use. If more time was available for the analysis, a somewhat larger sample could be employed. The amount of calculation required to complete the analysis is highly related to the number of households generated since the mode choices for each household must be determined for the base case and for each proposed transportation measure.

F. Input Data Development

Task 1 involves the development of base data for use in the analysis. Program HHGEN is used along with some manual methods to develop a sample of households whose behavior will be estimated. Also, the auto and transit level of service for each analysis zone is determined for use in Task 2.

Inputs to HHGEN are provided by published census data at the tract and block level. The output is a number (determined by the analyst) of households with characteristics selected at random from distributions based on the census data. These households are representative of the population of the study area. Six households represent the population of each zone. Within each analysis zone, three census blocks were selected at random and two households with at least one worker were generated for each block, based on data specific to the block and the tract in which it was located. The census data used as input to HHGEN for one of the blocks is shown in Tables III-1, III-2, and III-3, the following HHGEN worksheets (Figure III-3) illustrate the input format for the program. For this block, three households were generated, two of which had at least one worker. Figure III-4 illustrates the calculator output of HHGEN for each of three generated households.

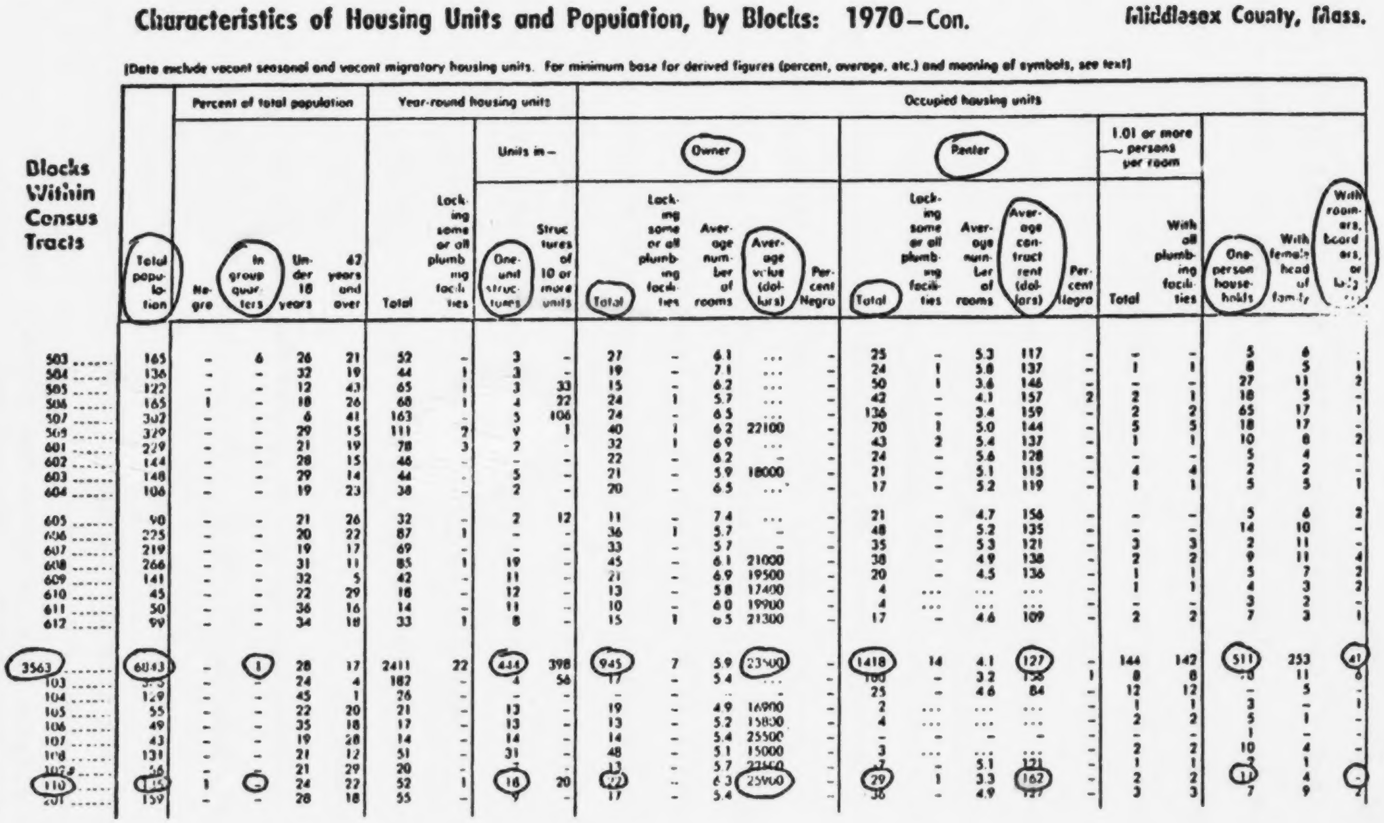
Step 2 involves assigning work places for each of the workers in the households generated by HHGEN. Eleven destination areas listed in the Census table "Social Characteristics of the Population"[1] were candidates for the work trip destination of workers in the household sample.

---

[1] This table reports work locations for tracts. Each block being analyzed within a tract is assumed to have the same workplace distribution.

TABLE III-1

Tract and Block Input Data from "Block Statistics", Boston Urban Area



Characteristics of Housing Units and Population, by Blocks: 1970—Con. **Middlesex County, Mass.**

[Data exclude vacant seasonal and vacant migratory housing units. For minimum base for derived figures (percent, average, etc.) and meaning of symbols, see text]

Blocks Within Census Tracts		Percent of total population				Year-round housing units		Units in—		Occupied housing units: Owner					Renter					1.01 or more persons per room				
	Total population	Negro	In group quarters	Under 18 years	62 years and over	Total	Lacking some or all plumbing facilities	One-unit structures	Structures of 10 or more units	Total	Lacking some or all plumbing facilities	Average number of rooms	Average value (dollars)	Percent Negro	Total	Lacking some or all plumbing facilities	Average number of rooms	Average contract rent (dollars)	Percent Negro	Total	With all plumbing facilities	One-person households	With female head of family	With roomers, boarders, or lodgers
503	165	–	6	26	21	52	–	3	–	27	–	6.1	...	–	25	–	5.3	117	–	–	–	5	6	–
504	136	–	–	32	19	44	1	3	–	19	–	7.1	...	–	24	1	5.8	137	–	1	1	8	5	1
505	122	–	–	12	43	65	1	3	33	15	–	6.2	...	–	50	1	3.6	146	–	–	–	27	11	2
506	165	1	–	18	26	68	1	4	22	24	1	5.7	...	–	42	–	4.1	157	2	2	1	18	5	–
507	302	–	–	6	41	163	–	5	106	24	–	6.5	...	–	136	–	3.4	159	–	2	2	65	17	1
509	329	–	–	29	15	111	2	9	1	40	1	6.2	22100	–	70	1	5.0	144	–	5	5	18	17	–
601	229	–	–	21	19	78	3	7	–	32	1	6.9	...	–	43	2	5.4	137	–	1	1	10	8	2
602	144	–	–	28	15	46	–	–	–	22	–	6.2	–	–	24	–	5.6	128	–	–	–	5	4	–
603	148	–	–	29	14	44	–	5	–	21	–	5.9	18000	–	21	–	5.1	115	–	4	4	2	2	–
604	106	–	–	19	23	38	–	2	–	20	–	6.5	...	–	17	–	5.2	119	–	1	1	5	5	1
605	90	–	–	21	26	32	–	2	12	11	–	7.4	...	–	21	–	4.7	156	–	–	–	5	6	2
606	225	–	–	20	22	87	1	–	–	36	1	5.7	–	–	48	–	5.2	135	–	–	–	14	10	–
607	219	–	–	19	17	69	–	–	–	33	–	5.7	–	–	35	–	5.3	121	–	3	3	2	11	–
608	266	–	–	31	11	85	1	19	–	45	–	6.1	21000	–	38	–	4.9	138	–	2	2	9	11	4
609	141	–	–	32	5	42	–	11	–	21	–	6.9	19500	–	20	–	4.5	136	–	1	1	5	7	2
610	45	–	–	22	29	18	–	12	–	13	–	5.8	17400	–	4	...	...	...	–	1	1	4	3	2
611	50	–	–	36	16	14	–	11	–	10	–	6.0	19900	–	4	...	...	...	–	–	–	3	2	–
612	99	–	–	34	18	33	1	8	–	15	1	6.5	21300	–	17	–	4.6	109	–	2	2	7	3	1
3563	6043	–	1	28	17	2411	22	444	398	945	7	5.9	23500	–	1418	14	4.1	127	–	144	142	511	253	41
103	[illegible]	–	–	24	4	182	–	4	56	17	–	5.4	...	–	100	–	3.2	[illegible]	1	8	8	[illegible]	11	6
104	129	–	–	45	1	26	–	–	–	–	–	...	–	–	25	–	4.6	84	–	12	12	–	5	–
105	55	–	–	22	20	21	–	13	–	19	–	4.9	16900	–	2	...	...	...	–	1	1	3	–	1
106	49	–	–	35	18	17	–	13	–	13	–	5.2	15800	–	4	...	...	...	–	2	2	5	1	–
107	43	–	–	19	28	14	–	14	–	14	–	5.4	25500	–	–	–	–	–	–	–	–	1	–	–
108	131	–	–	21	12	51	–	31	–	48	–	5.1	15000	–	3	...	...	...	–	2	2	10	4	–
[illegible]	56	–	–	21	29	20	–	7	–	13	–	5.7	[illegible]	–	7	–	5.1	121	–	1	1	2	1	–
110	[illegible]	1	–	24	22	52	1	18	20	22	–	6.3	25900	–	29	1	3.3	162	–	2	2	11	4	–
201	159	–	–	28	18	55	–	9	–	17	–	5.4	...	–	36	–	4.9	127	–	3	3	7	9	2

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TABLE III-2

Tract Income Data from Census Tracts, Boston SMSA

Income Characteristics of the Population: 1970—Continued

[Data based on sample, see text. For minimum base for derived figures (percent, median, etc.) and meaning of symbols, see text]

Census Tracts	Balance of SMSA in Middlesex County—Con.														
	Tract 3382	Tract 3383	Tract 3384	Tract 3385	Tract 3561	Tract 3562	Tract 3563	Tract 3564	Tract 3565	Tract 3566	Tract 3567	Tract 3571	Tract 3572	Tract 3573	Tract 3574
INCOME IN 1969 OF FAMILIES AND UNRELATED INDIVIDUALS															
All families	983	854	1 265	1 582	1 219	1 757	1 800	2 245	2 138	2 767	2 222	1 250	1 017	1 056	758
Less than $1,000	20	4	13	6	19	22	15	36	15	28	17	7	12	5	-
$1,000 to $1,999	23	5	9	-	9	63	25	22	52	26	15	18	11	4	5
$2,000 to $2,999	15	-	-	9	21	25	27	47	30	11	42	19	16	28	13
$3,000 to $3,999	20	8	12	17	28	27	91	45	39	64	50	23	6	29	7
$4,000 to $4,999	30	4	5	17	26	54	39	40	73	67	81	43	20	41	19
$5,000 to $5,999	53	6	12	37	40	96	69	52	34	85	59	27	27	40	31
$6,000 to $6,999	75	13	32	44	72	49	60	61	94	67	86	19	19	26	41
$7,000 to $7,999	57	9	9	38	69	103	143	78	89	142	110	35	71	62	36
$8,000 to $8,999	40	34	36	67	87	132	150	114	142	139	110	61	35	85	35
$9,000 to $9,999	94	41	21	36	178	91	129	123	139	164	120	68	44	48	17
$10,000 to $11,999	137	37	93	137	184	313	361	249	398	356	264	112	101	172	96
$12,000 to $14,999	178	114	112	220	213	332	320	331	410	700	376	143	113	241	143
$15,000 to $24,999	230	351	481	634	205	415	316	740	571	699	687	400	331	207	211
$25,000 to $49,999	6	183	312	202	28	35	55	267	50	209	186	213	159	61	79
$50,000 or more	5	45	118	38	-	-	-	40	-	10	19	62	52	7	25
Median income	$11 307	$19 330	$20 790	$17 571	$11 092	$11 333	$10 649	$14 316	$11 814	$13 005	$13 253	$16 250	$16 012	$11 660	$13 657
Mean income	$11 992	$22 794	$25 451	$18 950	$11 724	$11 872	$11 286	$15 963	$12 281	$14 034	$14 530	$19 041	$19 950	$13 117	$16 804
Families and unrelated individuals	1 297	1 078	1 437	1 944	1 467	2 397	2 459	2 545	2 635	3 640	3 203	1 459	1 226	1 349	986
Median income	$10 406	$16 877	$19 112	$14 509	$9 596	$9 996	$9 657	$13 271	$10 891	$11 419	$10 669	$14 297	$13 564	$10 595	$11 736
Mean income	$11 168	$19 675	$22 950	$16 483	$10 496	$10 285	$9 859	$14 877	$10 862	$12 110	$11 976	$17 439	$17 655	$11 556	$14 352
Unrelated individuals	364	224	172	362	248	640	668	360	499	873	981	209	209	293	228
Median income	$7 657	$5 667	$3 500	$3 864	$3 460	$5 297	$5 466	$5 971	$3 625	$5 604	$5 512	$5 982	$6 115	$5 392	$6 143
Mean income	$9 054	$7 787	$4 549	$5 525	$4 458	$5 926	$5 564	$6 753	$4 789	$6 010	$6 191	$7 859	$6 486	$5 930	$6 193

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TABLE III-3

Tract Auto Ownership Data from Census Tracts, Boston SMSA

Structural, Equipment, and Financial Characteristics of Housing Units: 1970—Continued

[Data based on sample, see text. For minimum base for derived figures (percent, median, etc.) and meaning of symbols, see text]

Census Tracts	Balance of SMSA in Middlesex County—Con.													
	Tract 3382	Tract 3383	Tract 3384	Tract 3385	Tract 3561	Tract 3562	Tract 3563	Tract 3564	Tract 3565	Tract 3566	Tract 3567	Tract 3571	Tract 3572	Tract 3573
1950 to 1959	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1949 or earlier	704	274	170	461	398	460	391	400	409	862	618	354	352	29
AUTOMOBILES AVAILABLE														
1	800	345	364	736	870	1 407	1 617	1 316	1 413	2 202	1 740	678	561	80
2	301	442	795	777	255	348	251	878	644	803	700	534	407	27
3 or more	28	145	152	155	44	52	16	149	111	135	112	94	74	2
None	99	112	10	159	236	532	379	158	292	377	469	114	71	21

Generation of Sample Households (HHGEN-1(A))

USER WORKSHEET 1

Tract 3563

Step	Procedure	Enter	Press	Display/Print
1	Set partition	2	2nd Op 17	799.19
2	Read banks 1a, 2a, and 3			
3	Enter tract data (from Table 2 of Block Statistics)	population = 6843	A	population
		% in grp. qtrs = 1	R/S	% in grp qtrs.
		# 1-unit = 444	R/S	# 1-unit
		# owner = 945	R/S	# owner
		avg value = $ 23500	R/S	avg value ($)
		# renter = 1418	R/S	# renter
		avg rent = $ 127	R/S	avg rent ($)
		# 1-person HH = 511	R/S	# 1-person HH
		# HH with RBL = 41	R/S	
4	Computes intermediate values (above values not retained)			# HH with RBL
5	Enter tract data from Census Tracts, Table P-4 and Table H-2	mean fam. Inc = 11286	R/S or D	Mean Fam. Inc. ($)
		median U.I. Inc. = 5466	R/S	Median U.I. Inc ($)
		# HH with 1 car = 1617	R/S or D'	# HH with one car
		# HH with 2 cars = 351	R/S	# HH with 2 cars
		# HH with 3+ cars = 16	R/S	# HH with 3+ cars
		# HH with 0 cars = 379	R/S	# HH with 0 cars
6	Compute adjustment factors (auto ownership values from step 5 not retained).			2+ cars adj. factor
	To review other adjustment factors:		RCL 19	2+ cars adj. factor
			RCL 18	1+ cars adj. factor
			RCL 17	Income adj. factor

FIGURE III-3

Sample HHGEN Worksheet

Generation of Sample Households (HHGEN-1(A))

USER WORKSHEET 2

Tract 3563

Block 110

Step	Proceoure	Enter	Press	Display/Print

7	Enter block data (from Block Statistics, Table 2). (To generate households based only on tract level data skip this step and go to step 9.)	population = 135
		% in grp.qtrs. = 0
		# 1-unit = 18
		# owner = 22
		avg.value = 25900
		# renter = 29
		avg rent = 162
		# 1-person HH = 11
		# HH with RBL = 0
			B
			R/S
			R/S
			R/S
			R/S
			R/S
			R/S
			R/S
			R/S
				population
				% in grp.qtrs.
				# 1-unit
				# owner
				avg. value
				# renter
				avg. rent
				# 1-person HH

8	Compute intermediate values (above values not retained).			# HH with RBL
9	Read banks 1b & 2b			
10	To make program write output automatically on magnetic cards (see step 12):		2nd st flg 3	
11	Generate n households (may be repeated as desired).	Number of households desired, n = 3	C	Household characteristics (printed only)
12	To write output onto magnetic cards (see step 10):	Place blank card into card reader during execution. After card is run through, replace for each household generated		
13	Review characteristics of household generated. Note: 2 cars = 2 or more 3 workers = 3 or more HTYPE = { 1 1-family house 0 multifamily		RCL 02 RCL 03 RCL 04 RCL 05 RCL 06	# cars household size HTYPE income ($1000) # workers

FIGURE III-3 (Cont.)

Generation of Sample Households (HHGEN-1(A)/780317/PGF)

USER WORKSHEET 3

Step	Procedure	Enter	Press	Print/Display
14	To generate households from a different block in the same tract, read banks 1a and 2a and go to step 7. To generate households from a different tract go to step 1.			

FIGURE III-3 (Cont.)

Three Households Generated

```
     1.        1F   1.  Lives in one-family unit
 19547.       INC       Income = $19,547
     1.       WKR       One worker
     5.      HHSZ       Household size = 5
     1.      CARS       Auto ownership = 1

     0.        MF   2.  Lives in multi-family unit
 15902.       INC       Income = $15,902
     2.       WKR       Two workers
     3.      HHSZ       Household size = 3
     2.      CARS       Auto ownership = 2

     0.        MF   3.  Lives in multi-family unit
  2907.       INC       Income = $2,907
     0.       WKR       Does not work
     1.      HHSZ       Household size = 1 (unrelated individual)
     0.      CARS       Auto ownership = 0
```

FIGURE III-4

Generated Household Characteristics

Each was assigned a zone number. The block for which the household generation process has been illustrated has the following distribution of work locations:

Destination	Number	Percent	Cumulative Percent
1	245	.087	.087
2	552	.195	.282
3	58	.021	.303
4	569	.201	.504
5	182	.064	.568
6	961	.340	.909
7	42	.015	.924
8	15	.005	.929
9	18	.030	.959
10	0	.000	.959
11	116	.041	1.000

Workers are assigned to work locations randomly. A random number between 0 and 1 generated by the programmable calculator, or obtained from a random number table, is assigned to each worker. The work location assigned to each worker is the first zone with cummulative frequency higher than the random number generated for the worker. The random numbers and corresponding work locations for the three workers in the block under analysis are:

Worker	Random Number	Work Location Zone
1	.2201	3
2	.5223	5
3	.1383	2

The work trip length for each worker was determined by measuring the centroid to centroid distance between the analysis block and the work location zone on a map of the urban area.

The estimation of auto and transit level of service (Steps 3 and 4) is accomplished manually. The level-of-service data items required for auto trips between each work trip origin/destination pair are in-vehicle travel time (IVTT), out-of-vehicle travel time (OVTT), and out-of-pocket travel costs (OPTC). Auto OVTT at the origin was taken as one minute for those living in multi-family structures, zero for single family houses. OVTT at the destinations ranged from one to five minutes, depending on parking availability and the density of development, as indicated by the height of the buildings at each destination. Auto IVTT was estimated based on empirical knowledge of the area, aided by field checks, and the trip length measures on a map of the area. Auto OPTC was taken as auto running cost (4 cents per mile) plus the average daily parking cost at the destinations, obtained by a brief telephone survey of parking lot owners.

Transit out-of-vehicle time at the work trip origin consists of walk time plus half the headway. Walk time was based on the specific household location within the zone (defined by the census block) and its distance from the bus route. Walk times at the destination were based on average distances between transit routes in the destination zone. Transfer times for transit were taken as one-half the headway. Transit in-vehicle time has two components: the time on the express route to the transfer point and time beyond the transfer point. The time beyond the transfer point to a given destination is assumed to be the same for workers in all zones and was kept constant when considering policies affecting the study corridor. The time to the transfer point depends on the block in which the worker lives and is affected by the proposed bus priority measures. The existing in-vehicle travel time for transit was estimated using bus schedules and average subway speeds. Transit fares were recorded, consistent with present values.

A completed Datasheet for one of the analysis zones is shown in Figure III-5. The market segment size for each worker is determined by dividing the total number of workers living in the census tract by the number of workers in the tract generated for forecasting use. (The table showing work locations for the tract also provides the total number of workers.) A similar datasheet is required for each of the remaining analysis zones.

Also in Step 4, the characteristics of the bus route operating in the corridor are ascertained. Figure III-6 shows the simplified set of stations, intersections and line segments used to represent the route.

FIGURE III-5

DATASHEET (2MODE-AGG-1(A)

	INPUT DATA										OUTPUT	
					AUTO			TRANSIT				
Worker #	Distance to Work	Yearly Income ($)	Autos/ Licensed Driver	Market Segment Size	IVTT (min)	OVTT (min)	OPTC (¢)	IVTT (min)	OVTT (min)	OPTC (¢)	Auto Volume	.ransit Volume
—	STO 07	STO 08	STO 09	STO 10	A	RUN	RUN	B	RUN	RUN		
1	5.6	16810	1	751	20	5	23	22.1	17	75		
2	5.3	11181	.5	751	19	2	21	25.1	17	75		
3	3	13205	1	751	13	4	162	14.1	8.5	25		
4	8	10731	.5	751	22	4	276	29.1	18	75		
5	5.5	8173	1	751	20	4	22	17.6	16	50		
6	3	8173	0	751	13	4	162	14.1	11.5	25		
TOTAL									2nd	C'		

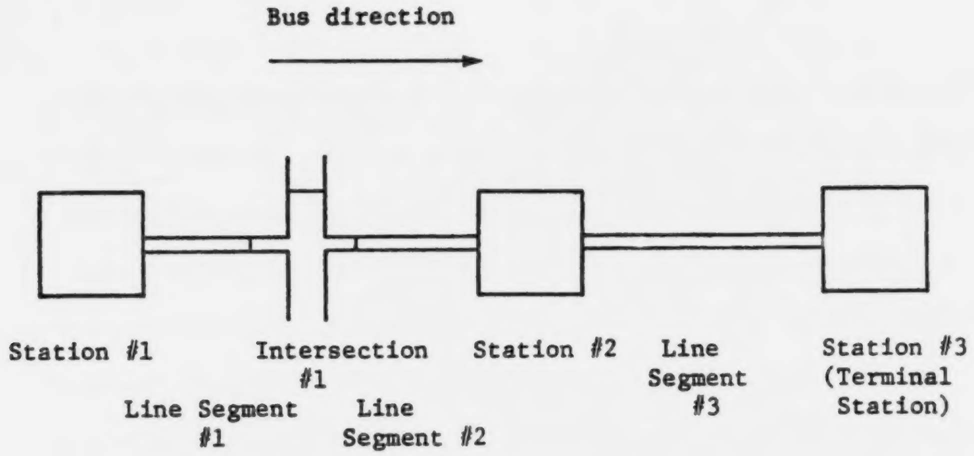

FIGURE III-6

Simplified Bus Route Representation

A more detailed representation would yield a more accurate picture of the operation of the route, but because bus operations along the route are not a critical factor in the analysis, this simplified model is adequate. For any analysis the stops and intersections used in BUS would be an aggregation of the actual stop and intersection pattern in order to keep the number of computations at a reasonable level.

Tables III-4, III-5, and III-6 show the station, intersection, and line segment characteristics required as input by BUS. The arrival rate at each station in passengers per minute is determined from the passenger demand calculated in Task II by 2 MODE-AGG and is assumed to be evenly split between the two stations and constant throughout the two-hour time period. The line segment lengths were determined from a map of the corridor, and assumptions concerning where the aggregated stops should be placed to best represent boarding patterns on the route. A constant auto volume of 1500 vph is assumed based on observations of the corridor. The number of lanes refers to the one-way lane capacity of the arterial. Traffic signal data could be obtained from the traffic engineering departments of the cities along the corridor, or even a brief observation of each signal or a sample of signals.

G. Description of Model Application

Base Modal Shares

Programs 2MODE-AGG and BUS are used to determine base transit shares and bus operating characteristics for each of the market segments (represented by one of the workers in the generated sample). Figure III-7 shows

TABLE III-4

Station Characteristics

Station #	1	2	3 (Terminal)
Arrival rate, V_{STA}	*	*	0.0
Fraction alighting, β	0.0	0.2	(1.0)

* To be determined by 2MODE-AGG

TABLE III-5

Line Segment Characteristics

Line Segment #	1	2	3
Length, d (ft.)	5000	1000	5000
Limiting speed, V_{LIM} (ft/min)	3080 (= 35 mph)	3080	3080
Auto volume, q_A (veh/min)	25	25	25
Number of lanes, n	2	2	2

TABLE III-6

Intersection Characteristics

Intersection #	1	
Signal cycle length, c (min)	1.17	
Fraction green time, λ	0.6	
Auto volume, q_A (veh/min)	25	
Number of lanes, n	2	

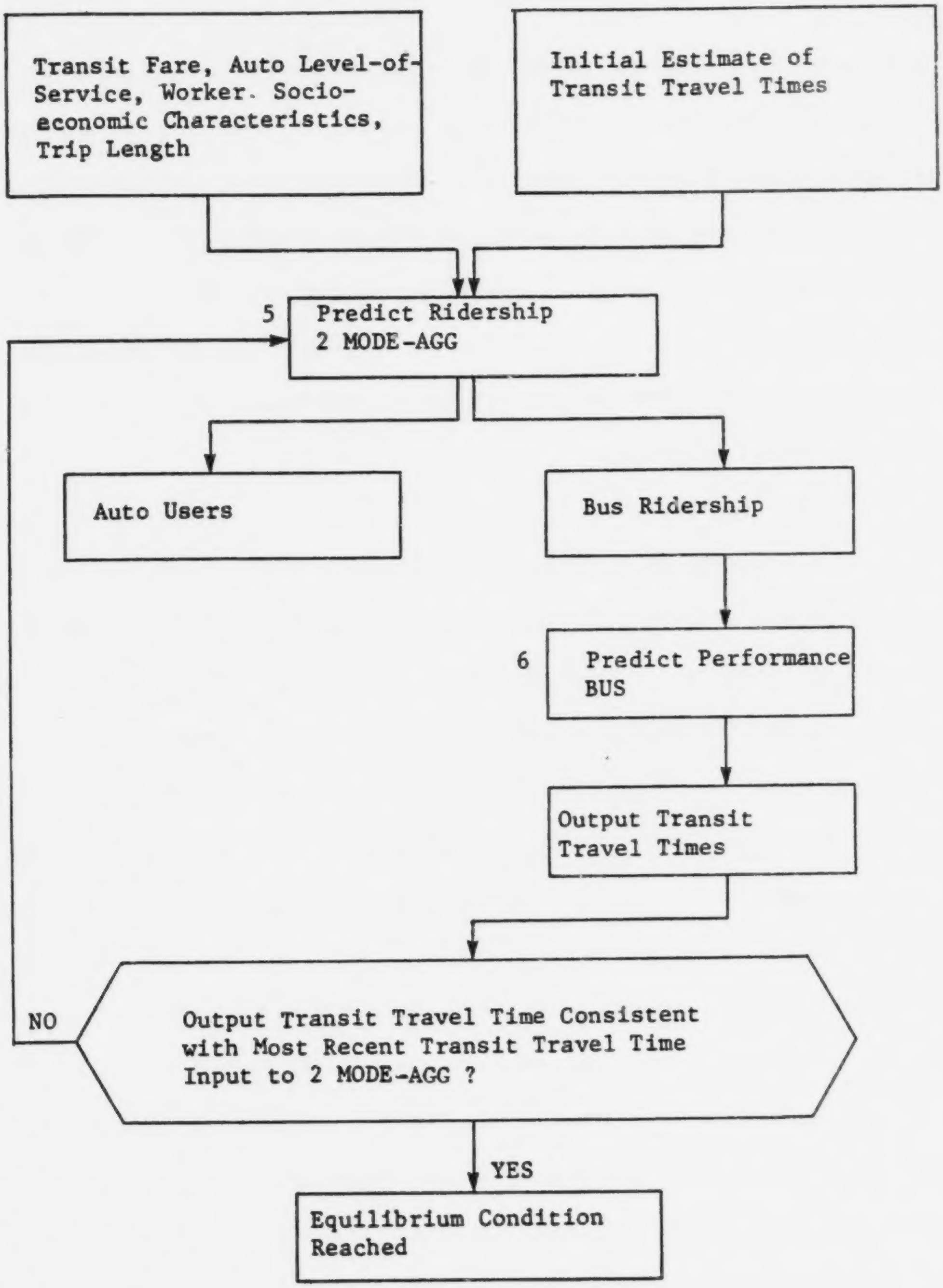
Transit Fare, Auto Level-of-Service, Worker Socio-economic Characteristics, Trip Length
Initial Estimate of Transit Travel Times
5
Predict Ridership 2 MODE-AGG
Auto Users
Bus Ridership
6
Predict Performance BUS
Output Transit Travel Times
NO
Output Transit Travel Time Consistent with Most Recent Transit Travel Time Input to 2 MODE-AGG ?
YES
Equilibrium Condition Reached

FIGURE III-7

Base Case Equilibrium Data Flows

the flow of data between the two programs, which are run iteratively until bus ridership and bus performance are in equilibrium. An initial bus ridership estimate is developed using 2MODE-AGG and this ridership is used to BUS to determine the level of service which could be offered at that ridership level. If the level of service predicted by BUS is significantly different from that used as input to 2MODE-AGG to predict bus ridership, a new run of 2MODE-AGG is made using the output of BUS for the level-of-service variables.

A 2MODE-AGG user worksheet for the first worker is shown in Figure III-8, illustrating the required order of input values and the outputs produced by the program for each worker. Program steps 5 through 7 are repeated 18 times to complete the initial estimate of base mode shares and transit volumes for use in program BUS. Figure III-9 shows completed program datasheets including transit and auto volumes for each worker. The total estimated work trip transit ridership is 2767, which translates into a passenger arrival rate of 11.5 passengers per minute at each of the two stations in the corridor.

This passenger demand rate, along with the other intersection, line segment, and station information collected for the bus route is entered into program BUS to determine if the level-of-service assumed in the estimation of bus pasenger demand is consistent with the service which can be provided at the resulting passenger demand rate.

Following the sample user worksheets for 2MODE-AGG is an illustrative run of BUS (Figure III-10). This sample run assumes a headway of ten minutes and a passenger arrival rate corresponding to a lower demand

USER WORKSHEET - BINARY MODE CHOICE WITH AGGREGATION (2 MODE-AGG-1(A)

Default values in [ ]. Trip variables take on one-way values.

Step	Procedure	Enter	Press	Print/Display
1.	Read card, sides A and B			
2.	Set printing option if using printer		2nd St flg 4	
3a.	Load default values of coefficients		E	
b.	Enter any alternate values desired:			
	(1) Coefficient of IVTT [-.03]	α_1 = ______	STO 01	
	(2) Coefficient of OVTT [-0.34]	α_2 = ______	STO 02	
	(3) Coefficient of OPTC [-50]	α_3 = ______	STO 03	
	(4) Coefficient of income [.0000895]	α_4 = ______	STO 04	
	(5) Coefficient of AALD [2.84]	α_5 = ______	STO 05	
	(6) Auto constant [-2]	const = ______	STO 06	
c.	List coefficients		2nd E'	α_1
			RUN*	α_2
			RUN*	α_3
			RUN*	α_4
			RUN*	α_5
			RUN*	const
4.	Initialize modal volume accumulation registers		2nd A'	
5.	Enter socio-economic characteristics			
	(1) Distance to work	d = 5.6	STO 07	
	(2) Yearly income ($)	Inc = 16810	STO 08	
	(3) Autos available/licensed driver	AALD = 1.0	STO 09	
	(4) Market segment size	Pop = 751	STO 10	

FIGURE III-8

Step	Procedure	Enter	Press	Print/Display
6.	Enter auto level-of-service data (1) In-vehicle travel time (min) (2) Out-of-vehicle travel time (min) (3) Out-of-pocket travel cost (¢) See note **.	 $IVTT_A$ = 20 $OVTT_A$ = 5 $OPTC_A$ = 23	 A RUN RUN	
7.	Enter transit level-of-service and compute modal shares and volumes. (1) In-vehicle travel time (min) (2) Out-of-veh. traveltime (min) (3) Out-of-pocket travel cost (¢) Read modal shares (P_m) and volumes (V_m). (Accumulates auto volume in register 98, transit volume in register 99.) See note **.	 $IVTT_T$ = 22.1 $OVTT_T$ = 17 $OPTC_T$ = 75	 B RUN RUN RUN * RUN * RUN *	P_A = ______ V_A = ______ P_T = ______ V_T = ______
8.	Repeat Steps 5-7 for every worker in sample (unchanged values in Step 5 need not be entered).	Repeat for all households		
9.	Print/display accumulated modal volumes		2nd C' RUN *	auto volume transit volume
10.	To do parametric variations over a sample go to Step 4.			

FIGURE III-8 (Cont.)

DATASHEET (2MODE-AGG-1(A)

Worker #	INPUT DATA										OUTPUT	
					AUTO			TRANSIT				
	Distance to Work	Yearly Income ($)	Autos/ Licensed Driver	Market Segment Size	IVTT (min)	OVTT (min)	OPTC (¢)	IVTT (min)	OVTT (min)	OPTC (¢)	Auto Volume	Transit Volume
—	STO 07	STO 08	STO 09	STO 10	A	RUN	RUN	B	RUN	RUN		
1	5.6	16810	1	751	20	5	23	22.1	17	75	724	27
2	5.3	11181	.5	751	19	2	21	25.1	17	75	645	106
3	3	13205	1	751	13	4	162	14.1	8.5	25	666	85
4	8	10731	.5	751	22	4	276	29.1	18	75	423	328
5	5.5	8173	1	751	20	4	22	17.6	16	50	690	61
6	3	8173	0	751	13	4	162	14.1	11.5	25	0	751
TOTAL									2nd	C'		

FIGURE III-9

DATASHEET (2MODE-AGG-1(A)

Worker #	INPUT DATA										OUTPUT	
					AUTO			TRANSIT				
	Distance to Work	Yearly Income ($)	Autos/ Licensed Driver	Market Segment Size	IVTT (min)	OVTT (min)	OPTC (¢)	IVTT (min)	OVTT (min)	OPTC (¢)	Auto Volume	Transit Volume
—	STO 07	STO 08	STO 09	STO 10	A	RUN	RUN	B	RUN	RUN		
13	12	23590	.5	332	38	2	48	43.9	12.5	75	295	37
14	7.5	8901	.5	332	26	3	30	29.9	10	50	226	106
15	5	15075	1	332	19	3	20	26.4	10.5	25	316	17
16	7.6	4651	1	332	27	5	31	34.4	21	75	310	22
17	7.5	10676	.33	332	26	3	30	29.9	16	50	222	110
18	5	12350	.5	332	19	3	20	26.4	11.5	25	263	69
TOTAL									2nd C'			

FIGURE III-9 (Cont.)

DATASHEET. (2MODE-AGG-1(A)

Worker #	INPUT DATA										OUTPUT	
					AUTO			TRANSIT				
	Distance to Work	Yearly Income ($)	Autos/ Licensed Driver	Market Segment Size	IVTT (min)	OVTT (min)	OPTC (¢)	IVTT (min)	OVTT (min)	OPTC (¢)	Auto Volume	Transit Volume
—	STO 07	STO 08	STO 09	STO 10	A	RUN	RUN	B	RUN	RUN		
7	6.5	14911	1	398	23	3	26	23.8	15	50	378	20
8	9.6	3782	0	398	28	3	90	34.3	17	50	0	398
9	9.6	8821	.5	398	30	6	280	28.3	10	50	107	291
10	.6	18173	.66	398	30	5	280	28.3	10	50	291	107
11	9	15338	.5	398	25	5	235	25.3	16.5	50	260	138
12	4	14457	.5	398	16	4	166	20.3	13.5	50	304	94
TOTAL									2nd C'			

FIGURE III-9 (continued)

USER INSTRUCTIONS - Bus Route Simulation [BUS-2(A),-2(B)]

A. Initialization

Step	Procedure	Enter	Press	Print/Display
A-1.	(TI 52) Load card 3 (TI 59) Set partition Load banks 1 and 2	6	$\boxed{\text{2nd}}$ $\boxed{\text{Op}}$ $\boxed{17}$	
A-2.	Initialize (stores default value automatically)		$\boxed{\text{2nd}}$ $\boxed{\text{A'}}$	
A-3.	Replace default values if desired *.	*(Use default values throughout; skip to Step A-4)*		
	(1) Random number seed [501; 0-199017]	Y = ______	$\boxed{\text{STO}}$ $\boxed{09}$	
	(2) Vehicle capacity per lane at saturation flow (vpm/lane) [30]	q_{CL} = ______	$\boxed{\text{STO}}$ $\boxed{11}$	
	(3) Boarding/alighting rate (min/pax) [0.0333]	b = ______	$\boxed{\text{STO}}$ $\boxed{12}$	
	(4) Bus capacity, seated and standing (pax) [75]	V_C = ______	$\boxed{\text{STO}}$ $\boxed{13}$	
	(5) Vehicle acceleration (ft/min^2) [15,840 = 3 mph/sec]	a = ______	$\boxed{\text{STO}}$ $\boxed{14}$	
	(6) Clearance time between busses (min) [0.25]	t_{CLR} = ______	$\boxed{\text{STO}}$ $\boxed{18}$	
	(7) Congestion curve factor [0.10,0.05-0.20]	J = ______	$\boxed{\text{STO}}$ $\boxed{00}$	
A-4.	Enter equivalent busses per minute, where	q_B = *0.1*	$\boxed{\times}$	
	q_B = busses per minute, and	k = *2*	$\boxed{=}$	*0.2*
	k = autos per bus equivalency factor [2]		$\boxed{\text{STO}}$ $\boxed{10}$	
A-5.	Set printing option if using printer		$\boxed{\text{2nd}}$ $\boxed{\text{St fl}}$ $\boxed{4}$	

FIGURE III-10

USER INSTRUCTIONS - Bus Route Simulation [BUS-2(A),-2(B)]

A. Initialization - p. 2

Step	Procedure	Enter	Press	Print/Display
A-6.	Set up the Detailed Simulation Record for the route being studied. The first page should be entitled "Header;" it records the passage of the bus through the origin station and the first line segment. The header is followed by a sequence of "Station" and "Intersection" Records in the same order as stations and intersections occur on the route. These records also include a line segment, since all stations and intersections are separated by line segments. Finally there should be a Terminal Station Record for the last station. Altogether there should be one record for each station and intersection modeled on the route. This series of records will record the movements of 4 busses through the route; to simulate more than 4 bus runs, a duplicate of the set of records is required for each 4 additional runs.	*The Detailed Simulation Record is organized and filled out in the pages following. The remaining pages of the User Instructions demonstrate the step-by-step procedure to be followed for one of each type of route segment.*		
A-7.	For the first run, values for t_{LAST}, the time the previous bus left the intersection, and V_{LEFT}, the number of passengers left unboarded at a station by the previous bus, must be initialized by the user. (Usually V_{LEFT} should be zero and t_{LAST} estimated knowing the average headway.)	*(V_{LEFT} is initialized at zero.* *t_{LAST} is initialized to the time the bus arrives minus the headway.)*		

USER INSTRUCTIONS - Bus Route Simulation [BUS-2(A),2(B)]

A. Initialization - p. 3

Step	Procedure	Enter	Press	Print/Display
A-8.	Simulate running the first bus through each segment of the route, recording times and passenger volumes on the Detailed Simulation Record compiled in step 7, following the User Worksheets B, C, D and E for line segments, intersections, stations, and terminal stations, respectively To run second and subsequent busses, see User Worksheet F.			

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*As many of these values as desired may be changed, and they may be changed at any time during the simulation. In particular, the vehicle capacity per lane (q_{CL}) and the congestion curve factor (J) may be different for different line segments over the route. Once changed, the new values remain in memory unless changed again.

USER INSTRUCTIONS - Bus Route Simulation [BUS-2(A),-2(B)]

B. Line Segment

(Data given here for Line Segment #1, for Bus #1)

Step	Procedure	Enter	Press	Print/Display
B-1.	(TI 52 only): Read card 1 (not necessary if card 1 already in memory)			
B-2.	Enter data:			
	(1) Time the previous bus left this segment	t_{LAST} = -9.45	$\boxed{\text{STO}}$ $\boxed{01}$	
	(2) Segment length (ft.)	d = 5000	$\boxed{\text{STO}}$ $\boxed{05}$	
	(3) Limiting speed (ft/min)	V_{LIM} = 3080	$\boxed{\text{STO}}$ $\boxed{06}$	
	(4) *Auto volume (vpm)	q_A = 25	$\boxed{\text{STO}}$ $\boxed{07}$	
	(5) *Number of lanes	n = 2	$\boxed{\text{STO}}$ $\boxed{08}$	
B-3.	Compute expected travel time (min) and cumulative clock time (min)		$\boxed{\text{A}}$ $\boxed{\text{RUN}}$ **	t_T = 1.949 t_{CUM} = 2.499
B-4.	Record t_T and t_{CUM} for this run on the simulation record. For the next run record t_{CUM} as t_{LAST} for this segment.	*(see Example*	*Simulation*	*Record, page 1.)*

* **Notes at end of Worksheet E.

USER INSTRUCTIONS - Bus Route Simulation [BUS-2(A),-2(B)]

C. Intersection

(Data given here for Intersection #1, for Bus #1)

Step	Procedure	Enter	Press	Print/Display
C-1.	(TI 52 only): Read card 1 (not necessary if card 1 is already in memory)			
C-2.	Enter data:			
	(1) Time the previous bus left this intersection	t_{LAST} = -7.50	STO 01	
	(2) Signal cycle length (min)	c = 1.17	STO 05	
	(3) Fraction of cycle length which is effective green time	λ = 0.60	STO 06	
	(4) *Auto volume (vpm)	q_A = 25*	STO 07	
	(5) *Number of lanes	n = 2*	STO 08	
C-3.	Computed expected delay (min)		B	t_T = 0.174
	and cumulative clock time (min)		RUN **	t_{CUM} = 2.674
C-4.	Record t_T and t_{CUM} on the simulation record for this run.	(See Example	Simulation	Record, p.2)
	For the next run, record t_{CUM} as t_{LAST} for this intersection.			

**Notes at end of Worksheet E.

USER INSTRUCTIONS - Bus Route Simulation [BUS-2(A),-2(B)]

D. Station

(Data given here for Station #1, Bus #1)

Step	Procedure	Enter	Press	Print/Display
D-1.	(TI 52 only:) Read card 2.			
D-2.	Enter data:			
	(1) Time the previous bus left this station	t_{LAST} = -10	$\boxed{\text{STO}}$ $\boxed{01}$	
	(2) Number of pax left unboarded as the last bus left this station	V_{LEFT} = 0	$\boxed{\text{STO}}$ $\boxed{02}$	
	(3) Mean passenger arrival rate (pax/min)	V_{STA} = 1.2	$\boxed{\text{STO}}$ $\boxed{05}$	
	(4) Fraction of pax on the vehicle alighting at this station	β = 0	$\boxed{\text{STO}}$ $\boxed{06}$	
D-3.	Compute:			
	(1) Number of pax left unboarded		$\boxed{\text{C}}$	V'_{LEFT} = 0
	(2) Number of pax boarding		$\boxed{\text{RUN}}$ **	V_{ON} = 9
	(3) Number of pax alighting		$\boxed{\text{RUN}}$ **	V_{OFF} = 0
	(4) Total delay (min)		$\boxed{\text{RUN}}$ **	t_T = .550
	(5) Cumulative clock time (min)		$\boxed{\text{RUN}}$ **	t_{CUM} = .550
	Recall total volume on bus		$\boxed{\text{RCL}}$ $\boxed{16}$	V' = 9
D-4.	Record the above values on the simulation record for this run. For the next run record V'_{LEFT} as V_{LEFT} and record t_{CUM} as t_{LAST} for this station.	*(See Example Simulation Record, p.1.)*		

** Notes at end of worksheet E.

USER INSTRUCTIONS - Bus Route Simulation [BUS-2(A),-2(B)]

E. Terminal Station

(Data given here for Terminal Station, Bus #1)

Step	Procedure	Enter	Press	Print/Display
E-1.	(TI 52 only): Read card 3.			
E-2.	Compute:			
	(1) Time spent unloading pax (min)		$\boxed{\text{2nd}}$ $\boxed{\text{E}'}$	t_T = *0.366*
	(2) Cumulative clock time (min)		$\boxed{\text{RUN}}$**	t_{CUM} = *5.996*
	(3) Running time over the whole route for this bus (min)		$\boxed{\text{RUN}}$**	t_R = *5.996*
	(4) Total # pax carried in this run		$\boxed{\text{RUN}}$**	V_{CUM} = *13*
E-3.	Record the above values on the simulation record.	*(See Example Simulation Record, p. 4.)*		

---

*Items (4) and (5) need not be entered if q_A and n have the same values as when they were last entered, whether in a line segment or an intersection, and are still stored in registers 07 and 08.

** $\boxed{\text{R/S}}$ on TI 59. Not to be pressed if printing option is set.

Simulation Record - p.1

Header

		Bus Simulation Records				Press
	INPUT/ OUTPUT	Bus # 1 t_o = 0.0	Bus # 2 t_o = 10.0	Bus # ____ t_o = ____	Bus # ____ t_o = ____	2nd B'
STATION # 1	ENTER					
(card 2)	t_{LAST}	= -10.0	= .550	=	=	STO 01
	V'_{LEFT}	= 0	= 0	= 0	=	STO 02
ENTER | PRESS	RECORD					C
V_{STA} = 1.2 | STO 05	V'_{LEFT}	= 0	= 0	=	=	
β = 0 | STO 06	V_{ON}	= 9	= 8	=	=	RUN **
	V_{OFF}	= 0	= 0	=	=	RUN **
	t_T	= 0.550	= .516	=	=	RUN **
	t_{CUM}	= 0.550	= 10.516	=	=	RUN **
	V	= 9	= 8	=	=	RCL 16
		↓	↓	↓	↓	
LINE SEGMENT # 1	ENTER					
(card 1)	t_{LAST}	= -9.45 (estimated as 0.550 - 10.0)	= 2.499***	= ***	= ***	STO 01
						A
ENTER | PRESS	RECORD					
d = 5000 | STO 05	t_T	= 1.949	= 1.949	=	=	
V_{LIM} = 3080 | STO 06	t_{CUM}	= 2.499	= 12.466	=	=	RUN **
q_A = 25 | STO 07	V	= (9)	= (8)	=	=	RCL 16
n = 2 | STO 08	(V remains unchanged during line segments and intersections)					

** Not to be pressed if printing option is set. R/S on TI 59.

*** t_T is usually the same for every bus, so it is sufficient to enter t_T (as calculated for the first bus) and press D. See sheet F of the User Instructions.

Simulation Record - p.2

Intersection

	INPUT/ OUTPUT	Bus Simulation Records Bus # 1	 Bus # 2	 Bus # ___	 Bus # ___	Press
INTERSECTION # 1 (card 1)	ENTER					
	t_{LAST}	= -7.50	= 2.674***	= ___***	= ___***	STO 01 B
	RECORD					
	t_T	= 0.174	= 0.174	= ___	= ___	
	t_{CUM}	= 2.674	= 12.640	= ___	= ___	RUN**
	V	= (9)	= (8)	= ___	= ___	RCL 16

ENTER	PRESS
c = 1.17	STO 05
λ = 0.6	STO 06
q_A = (25)*	STO 07
n = (2)*	STO 08

(q_A and n are the same as for Line Segment #1 and thus need not be entered again.)

	INPUT/ OUTPUT	Bus # 1	Bus # 2	Bus # ___	Bus # ___	Press
LINE SEGMENT # 2 (card 1)	ENTER	↓	↓	↓	↓	
	t_{LAST}	= -7.33	= 3.230***	= ___***	= ___***	STO 01 A
	RECORD					
	t_T	= .557	= .557	= ___	= ___	
	t_{CUM}	= 3.230	= 13.199	= ___	= ___	RUN**
	V	= (9)	= (8)	= ___	= ___	RCL 16

ENTER	PRESS
d = 1000	STO 05
V_{LIM} = 3080	STO 06
q_A = (25)*	STO 07
n = (2)*	STO 08

---

*Need not be entered if values are the same as when last entered

**R/S on TI 59. Not to be pressed if printing option is set

***See note on Header sheet.

Simulation Record - p.3

Station

		Bus Simulation Records				Press
	INPUT/ OUTPUT	Bus # 1	Bus # 2	Bus #	Bus #	
STATION # 2	ENTER					
(card 2)	t_{LAST}	= -6.77	= 3.68	=	=	STO 01
	V'_{LEFT}	= 0	= 0	=	=	STO 02
ENTER / PRESS	RECORD					C
V_{STA} = 0.6 / STO 05	V'_{LEFT}	= 0	= 0	=	=	
β = 0.2 / STO 06	V_{ON}	= 4	= 5	=	=	RUN **
	V_{OFF}	= 2	= 1	=	=	RUN **
	t_T	= .450	= .450	=	=	RUN **
	t_{CUM}	= 3.680	= 13.647	=	=	RUN **
	V	= 11	= 12	=	=	RCL 16
		↓	↓	↓	↓	
LINE SEGMENT # 3	ENTER					
(card 1)	t_{LAST}	= -6.32	= 5.63*** (See note on User Instructions sheet F)	= ***	= ***	STO 01 A
ENTER / PRESS	RECORD					
d = 5000 / STO 05	t_T	= 1.949	= 1.949	=	=	
V_{LIM} = 3080 / STO 06	t_{CUM}	= 5.630	= 15.596	=	=	RUN **
q_A = (25)* / STO 07	V	= (11)	= (12)	=	=	RCL 16
n = (2)* / STO 08						

---

*Need not be entered if values are the same as when last entered

**R/S on TI 59. Not to be pressed if printing option is set

***See note on header sheet.

Simulation Record - p.4

Terminal Station

		Bus Simulation Records				Press
	INPUT/ OUTPUT	Bus # 1	Bus # 2	Bus # ___	Bus # ___	
TERMINAL STATION (card 3)	RECORD					2nd E'
	t_T	= .366	= 0.400	=	=	
	t_{CUM}	= 5.996	= 15.996	=	=	RUN **
	t_R	= 5.996	= 5.996	=	=	RUN **
	V_{CUM}	= 13	= 13	=	=	RUN **

** R/S on TI 59. Not to be pressed if printing option is set level than that predicted by 2MODE-AGG. It is included for illustrative purposes as the actual BUS runs for the corridor analysis were not available. The following input values and procedures would be changed for the analysis of a route with three-minute headways and a passenger demand rate of 11.5 passengers per minute:

- Step A-4 $- q_B = 0.33$
- Step B-2 (1) $t_{LAST} = -2.45$
- Step C-2 (2) $t_{LAST} = -0.50$
- Step D-2 (1) $t_{LAST} = -3.0$
- Step D-2 (3) $V_{STA} = 11.5$
- Computations in D-3 and E-2 would reflect the higher demand rate rate and bus frequencies.
- Additional line segments and one additional station would be included in the run.
- The simulation record would also reflect the above-mentioned changes.

To achieve equilibrium for the base case conditions on the bus route, two iterations (two runs of 2MODE-AGG and BUS) were required. The final results predicted average bus loads of 57 passengers into the transfer point, with just over 28 minutes required to run the entire length of the route.

Step 7 of the analysis involves the prediction of incremental changes in bus ridership due to the proposed bus priority measures. To estimate the level-of-service impact of the two measures, program BUS is run with the following modifications to the base case:

- increased effective green time and cycle length at the intersection to reflect the preferential signal control for buses (applies to both proposed priority strategies).
- On each line segment and at the intersection, the number of lanes is reduced to one and auto volume to zero to represent the reserved bus lane.

From the two runs of BUS under bus priority conditions (one run for each policy being analyzed), estimates of the improvement in bus IVTT were obtained.

Program 3MODE(VAN)-AGG is then used to determine the incremental increase in bus ridership which would result from the predicted improvement in bus level of service. Because no information on carpooling activity is available for the study corridor, a two-mode (auto and transit) model is incorporated into the 3MODE(VAN)-AGG program by changing the mode choice model coefficients. This is accomplished by entering user-specified coefficients in Step 3 of the program. The coefficients of the two-mode model are:

- IVTT: -.03
- OVTT: -.11
- OPTC: -.005

The coefficients required by 3MODE(VAN)-AGG are IVTT, OVTT/DIST, and OPTC/Y, whre "DIST" is round trip length and "Y" is household income. In order to enter the coefficients as shown above, the OVTT and OPTC coefficient must be adjusted and entered separately for each market segment being analyzed as follows:

OVTT/DIST = .11 x trip length

OPTC/Y = -.005 x household income.

The proper coefficients for market segment 1 would be:

$$OVTT/DIST = -.11 \times 11.2 = -1.23$$

$$OPTC/Y = -.005 \times 16,810 = -84.5$$

None of the other optional 3MODE(VAN)-AGG program subroutines are used in the analysis of the bus priority strategies. The only other non-standard procedure used is representing the overall auto mode share by the "drive alone" share in the program rather than by a drive-alone and a carpool share.

A set of user worksheets with entries for one of the market segments under analysis, reflecting the signal preemption only priority option follows. The data used to develop the information on Worksheet C-1 (Figure III-11) is available from the 2MODE-AGG datasheet for the equilibrium base case. The auto and transit volumes predicted by 2MODE-AGG are used to calculate the base work trip model shares for "drive alone" and transit. The run of BUS reflecting the alternative bus priority measures provides the estimated change in transit in-vehicle travel time shown on Worksheet C-2 (Figure III-12). This is assumed to be the only significant change in level of aservice associated with the bus priority measures; all other level-of-service changes are zero. Worksheet C-4 (Figure III-13) is used to organize the data for input to the 3MODE(VAN)-AGG and provides step-by-step directions for program execution.

3MODE(VAN)-AGG must be run 18 times (once for each representative worker) with the results being accumulated in the program automatically. After the bus ridership level for each bus priority alternative has been determined, the new passenger demand rate per hour is used as input for

FIGURE III-11

WORKSHEET C-1

BASE DATA

POLICY: Signal Pre-Emption

								Base Work Trip Modal Shares				
Population Subgroup	Average round Trip Length (mi)	Annual Household Income ($)	Average Carpool Size	Population	Average Vanpool Size	Vanpool Circuity Factor	Drive Alone	Carpool	Transit	Vanpool	Other
1	11.2	16,810	(2.5)	751	10	1.5	.964	-	.036	-	-

WORKSHEET C-2

FIGURE III-12

POLICY: Signal Pre-Emption

CHANGES IN TRANSPORTATION LEVEL OF SERVICE

(all data represent round trips)

Population Subgroup	Drive Alone			Carpool				Transit			Vanpool			
	In-Vehicle Travel Time $\Delta IVTT_{da}$ (min.)	Out-of-Vehicle Travel Time $\Delta OVTT_{da}$ (min.)	Out-of-Pocket Travel Cost $\Delta OPTC_{da}$ (¢)	In-Vehicle Travel Time $\Delta IVTT_{cp}$ (min.)	Out-of-Vehicle Travel Time $\Delta OVTT_{cp}$ (min.)	Out-of-Pocket Travel Cost $\Delta OPTC_{cp}$ (c)	Carpool Promotion & Matching Incentives (0,1)	In-Vehicle Travel Time $\Delta IVTT_{t}$ (min.)	Out-of-Vehicle Travel Time $\Delta OVTT_{t}$ (min.)	Out-of-Pocket Travel Cost $\Delta OPTC_{t}$ (c)	In-Vehicle Travel Time $\Delta IVTT_{vp}$ (min.)	Out-of-Vehicle Travel Time $\Delta OVTT_{vp}$ (min.)	Out-of-Pocket Travel Cost $\Delta OPTC_{vp}$ (¢)	Vanpool Promotion & Matching Incentives (0,1)
1	0	0	0	0	0	0	0	-8.8	0	0	0	0	0	0

WORKSHEET C-4 PROGRAM STEPS

639.39
(3MODE(VAN)-AGG-2(B)/7900110/ESE)

USER INSTRUCTIONS

STEP	PROCEDURE	ENTER	PRESS			DISPLAY
1	Read card(s) - partitioning is 639.39					
2	Initialize Storage Registers and store					
	default Coefficients		A			.29
	If default coefficients are used, skip					
	to STEP 4					
3	OPTIONAL - Enter user-supplied coefficients					
3a	coefficient of IVTT-DA mode	$\theta_1DA = -.03$	STO	00		
3b	coefficient of OVTT/DIST-DA mode	$\theta_2DA = -1.23$	STO	01		
3c	coefficient of OPTC/Y-DA mode	$\theta_3DA = -8.45$	STO	02		
3d	coefficient 4-DA mode	$\theta_4DA = 0$	STO	03		
3e	coefficient 5-DA mode	$\theta_5DA = 0$	STO	04		
3f	coefficient of IVTT-SR mode	$\theta_1SR = 0$	STO	05		
3g	coefficient of OVTT/DIST-SR mode	$\theta_2SR = -.03$	STO	06		
3h	coefficient of OPTC/Y-SR mode	$\theta_3SR = -1.23$	STO	07		
3i	coefficient of incentives-SR mode	$\theta_4SR = -8.45$	STO	08		
3j	coefficient 5-SR mode	$\theta_5SR = 0$	STO	09		
3k	coefficient of IVTT-T mode	$\theta_1T = -.03$	STO	10		
3l	coefficient of OVTT/DIST-T mode	$\theta_2T = -1.25$	STO	11		
3m	coefficient of OPTC/Y-T mode	$\theta_3T = -8.45$	STO	12		
3n	coefficient 4-T mode	$\theta_4T = 0$	STO	13		
3o	coefficient 5-T mode	$\theta_5T = 0$	STO	14		
	IF A MISTAKE IS MADE, BEGIN AGAIN AT STEP 3a					
4	Enter market segment data (from worksheet C-1)					
4a	round trip distance in miles ≠ 0	DIST = 11.2	R/S			
4b	household average annual income in $ ≠ 0	Y = 16.810	R/S			
	enter "1" if income is not needed for this					
	segment.					
4c	Average carpool occupancy ≠ 0	$OCC_{CP} = 2.5$	R/S			
	Default = 2.5					
4d	Market segment population	POP = 751	R/S			

FIGURE III-13

WORKSHEET C-4
(continued)
(3MODE(VAN)-AGG-2(B)/790110/ESE)

USER INSTRUCTIONS

STEP	PROCEDURE	ENTER	PRESS			DISPLAY
4e	Average vanpool occupancy ≠ 0 default -- 10	OCC_{VP} = 10	R/S			
4f	Vanpool circuity factor ≠ 0 default -- 1.5	CIRC = 1.5	R/S			
	If a mistake is made, press $\boxed{C}$ and begin with STEP 4a					
	If carpool subroutine is not used, go to STEP 6					
5	OPTIONAL - Carpool Subroutine (data from worksheet C-3)		2nd	C'		38
5a	Enter average occupancies of two classes of carpools:					
	1. Average occupancy carpool class 1	OCC_{CP1}= ___	R/S			
	2. Average occupancy carpool class 2	OCC_{CP2}= ___	R/S			
5b	Enter level of service and mode share data					
	1. ΔIVTT - carpool class 1	Δ = ______	R/S			
	2. ΔOVTT - carpool class 1	Δ = ______	R/S			
	3. ΔOPTC - carpool class 1	Δ = ______	R/S			
	4. ΔINCENT - carpool class 1 (0/1)	Δ = ______	R/S			
	5. Δ_5 - carpool class 1**	Δ = ______	R/S			
	6. carpool class 1 share as a fraction of all carpools *	S_{CP1}= ______	R/S	2nd	E'	
	If a mistake is made, press $\boxed{C'}$ and begin with STEP 5a					
	7. ΔIVTT- carpool class 2	Δ = ______	R/S			
	8. ΔOVTT - carpool class 2	Δ = ______	R/S			
	9. ΔOPTC- carpool class 2	Δ = ______	R/S			
	10. Δ INCENT - carpool class 2 (0/1)	Δ = ______	R/S			
	11. Δ_5 - carpool class 2**	Δ = ______	R/S			
	12. carpool class 2 share as a fraction of all carpools*	S_{CP2} = ______	R/S			
	If a mistake is made, press $\boxed{C'}$ and begin with STEP 5a					

---

* These two values should sum to 1.0

** If default coefficients are used, these Δ's must equal zero.

WORKSHEET C-4

(continued)

(3MODE(VAN)-AGG-2(B)/790110/ESE)

USER INSTRUCTIONS

STEP	PROCEDURE	ENTER	PRESS			DISPLAY
5c	carpool subroutine results:					
	1. New average occupancy for all carpools		R/S			*OCC_{CP} = ______
	2. New carpool change in level of service (for all carpools)					
	Enter ΔLOS for carpool class 1	Δ_{CP1} = ______	R/S			
	Enter ΔLOS for carpool class 2	Δ_{CP2} = ______	R/S			Δ_{CP} = ______
	To repeat for another change in level of service, press $\boxed{D'}$ and repeat STEP 5c2.		2nd	D'		
	Step 5 results can also be recorded on Worksheet C-5.					
	To continue with STEP 6		R/S			
6	Store modal shares for this market segment (from Worksheet C-1)					
6a	Base drive-alone share as a fraction ** (i.e., .645, not 64.5)	S_{DA} = .964	R/S			
6b	Base carpool share as a fraction **	S_{CP} = 0	R/S			
6c	Base transit share as a fraction **	S_T = .036	R/S			
6d	Base vanpool share as a fraction **	S_{VP} = ______	R/S			
6e	Base "other" share as a fraction **	S_O = ______	R/S			
6f	Base autos per worker		R/S			A/W = ______
	If a mistake is made, press $\boxed{GO\ TO}$ $\boxed{1/X}$ and begin with STEP 6a.					
6g	Base VMT		R/S			VMT_{TOT} = ______
	If vanpool subroutine is not used, go to STEP 8					
7	OPTIONAL Vanpool Subroutine					
	If VP = 0 in 6d and the revised vanpool share ≠ 0, enter a "base" vanpool share on which to pivot. Defaults -- .14 for firms with ≤ 2000 employees .06 for firms with ≥ 2000 employees	S_{VP} = ______	R/S			
	If a mistake is made, press $\boxed{B'}$ and repeat STEP 7					

---

* printed but not displayed

** these five fractions must sum to 1

WORKSHEET G-4
(continued)

(3MODE(VAN)-AGG-2(B)/790110/ESE)

USER INSTRUCTIONS

STEP	PROCEDURE	ENTER	PRESS			DISPLAY
8	Enter changes in level of service from Worksheet C-2)		D			
	If there are NO changes in level of service, Press $\boxed{B}$ and go to STEP 10; otherwise,		B			
	Drive Alone changes:					
8a	$\Delta IVTT_{DA}$	Δ = 0	R/S			
8b	$\Delta OVTT_{DA}$	Δ = 0	R/S			
8c	$\Delta OPTC_{DA}$	Δ = 0	R/S			
8d	$\Delta 4_{DA}$ **	Δ = 0	R/S			
8e	$\Delta 5_{DA}$ **	Δ = 0	R/S			
	If there are no additional changes in LOS, press $\boxed{B}$ and go to STEP 10		B			
	Carpool changes from Step 5 or Worksheet C-5 if optional STEP 5 was used:					
8f	$\Delta IVTT_{CP}$	Δ = 0	R/S			
8g	$\Delta OVTT_{CP}$	Δ = 0	R/S			
8h	$\Delta OPTC_{CP}$	Δ = 0	R/S			
8i	$\Delta INCENT_{CP}$ *	Δ = 0	R/S			
8j	$\Delta 5_{CP}$ **	Δ = 0	R/S			
	If there are no additional changes in LOS, press $\boxed{B}$ and go to STEP 10		B			
	Transit changes:					
8k	$\Delta IVTT_{T}$	Δ = -8.8	R/S			
8l	$\Delta OVTT_{T}$	Δ = 0	R/S			
8m	$\Delta OPTC_{T}$	Δ = 0	R/S			
8n	$\Delta 4_{T}$ **	Δ = 0	R/S			
8o	$\Delta 5_{T}$ **	Δ = 0	R/S			
	If a mistake is made, press $\boxed{\text{GO TO}}$ $\boxed{1/X}$ and begin at STEP 6a					
	If the vanpool share in 6d = 0 and STEP 7 was not used, GO TO STEP 10					
9	OPTIONAL: Enter vanpool change in LOS (from Worksheet C-2)					
9a	$\Delta IVTT_{VP}$	Δ = ______	R/S			
9b	$\Delta OVTT_{VP}$	Δ = ______	R/S			
9c	$\Delta OPTC_{VP}$	Δ = ______	R/S			
9d	$\Delta INCENT_{VP}$ ***	Δ = ______	R/S			
9e	$\Delta 5_{VP}$ **	Δ = ______	R/S			

* This must equal 0 or 1 unless the carpool subroutine is used, in which case it must be between 0 and 1 inclusive.

** If default coefficients are used, these Δ's must equal 0.

*** 9d must equal zero if STEP 7 was used.

WORKSHEET C-4

(continued)

(3MODE(VAN)-AGG-2(B)/790110/ESE)

USER INSTRUCTIONS

STEP	PROCEDURE	ENTER	PRESS			DISPLAY
10	Market segment results		B			
10a	New DA share *					S'_{DA} = ______
10b	New DA volume					VOL'_{DA}= ______
10c	New DA VMT		R/S			VMT'_{DA}= ______
10d	New CP share *		R/S			S'_{CP} = ______
10e	New CP volume SEE SUMMARY TABLE					VOL'_{CP}= ______
10f	New CP VMT		R/S			VMT'_{CP}= ______
10g	New T share *		R/S			S'_{T} = ______
10h	New T volume					VOL'_{T} = ______
10i	New VP share *		R/S			S'_{VP} = ______
10j	New VP volume					VOL'_{VP}= ______
10k	New VP VMT		R/S			VMT'_{VP}= ______
10l	New Other share *		R/S			S'_{O} = ______
10m	New VMT for this market segment					VMT'_{TOT}= ______
10n	New Autos per worker * These results can also be recorded on Worksheet C-6		R/S			A/W' = ______
11	To analyze another market segment and have the results aggregated with previously analyzed market segments, press $\boxed{C}$ and GO TO STEP 4		C			
	To print** aggregated results of all previous market segments, press $\boxed{E}$		E			
						$\Sigma VOL'_{DA}$= ______
						$\Sigma VMT'_{DA}$= ______
						$\Sigma VOL'_{CP}$= ______
						$\Sigma VMT'_{CP}$= ______
						$\Sigma VOL'_{T}$ = ______
						$\Sigma VOL'_{VP}$= ______
						$\Sigma VMT'_{VP}$= ______
						ΣVMT_{TOT}= ______
						$\Sigma VMT'_{TOT}$= ______
	These results can also be recorded on Worksheet C-6					$\Delta\Sigma VMT_{TOT}$= ______
	To analyze a new policy (no aggregation with previous market segments), press $\boxed{A}$ and GO TO STEP 2. (Since this sets memories to zero, data from previously tested policies must be copied before A is pressed, and user-supplied coefficients, if any, must be re-entered in STEP 3.		A			$\%\Delta\Sigma VMT_{TOT}$= ______

* Printed but not displayed

**See Comments (Section 4) for retrieving data without a printer.

another run of BUS. Each program is run iteratively, using the output of the previous program as part of the program input until equilibrium is reached between bus ridership and bus level of service. Figure III-14 illustrates this iterative procedure.

Tables III-7 and III-8 show the average bus travel time and ridership predictions developed for the base case and the two levels of bus priority treatment. The results were compiled from information recorded on Worksheet C-6 for each of the 18 representative worktrips or market segments and the simulation records from Program BUS. Market segments 1 through 6 represented origin Zone I; 7 through 12, Zone II; and 13 through 18, Zone III. These results are used as input to the Step 8 analysis of bus energy consumption and Step 9 analysis of emissions. 3MODE(VAN)-AGG also calculates total work trip auto VMT for the base and alternative cases. However, in converting the program to a two-mode model, all auto person trips were classified as drive-alone for predictive purposes. This leads to an overestimate of auto VMT because each auto person trip is translated into a vehicle trip for VMT calculation purposes, while in actuality, the auto occupancy for worktrips in the corridor is somewhat greater than 1.0. Assuming the national average of 1.2,[1] the auto VMT calculated by 3MODE(VAN)-AGG must be divided by 1.2 for the base and each alternative case.

Program ENERGY predicts the per-hour fuel consumption rate of a bus route. It also calculates the number of buses required to cover the route and the actual layover time which would occur with that number of

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[1] Alternatively, auto occupancy estimation techniques contained in NCHRP Report 187 could be used to determine the approximate corridor auto occupancy.

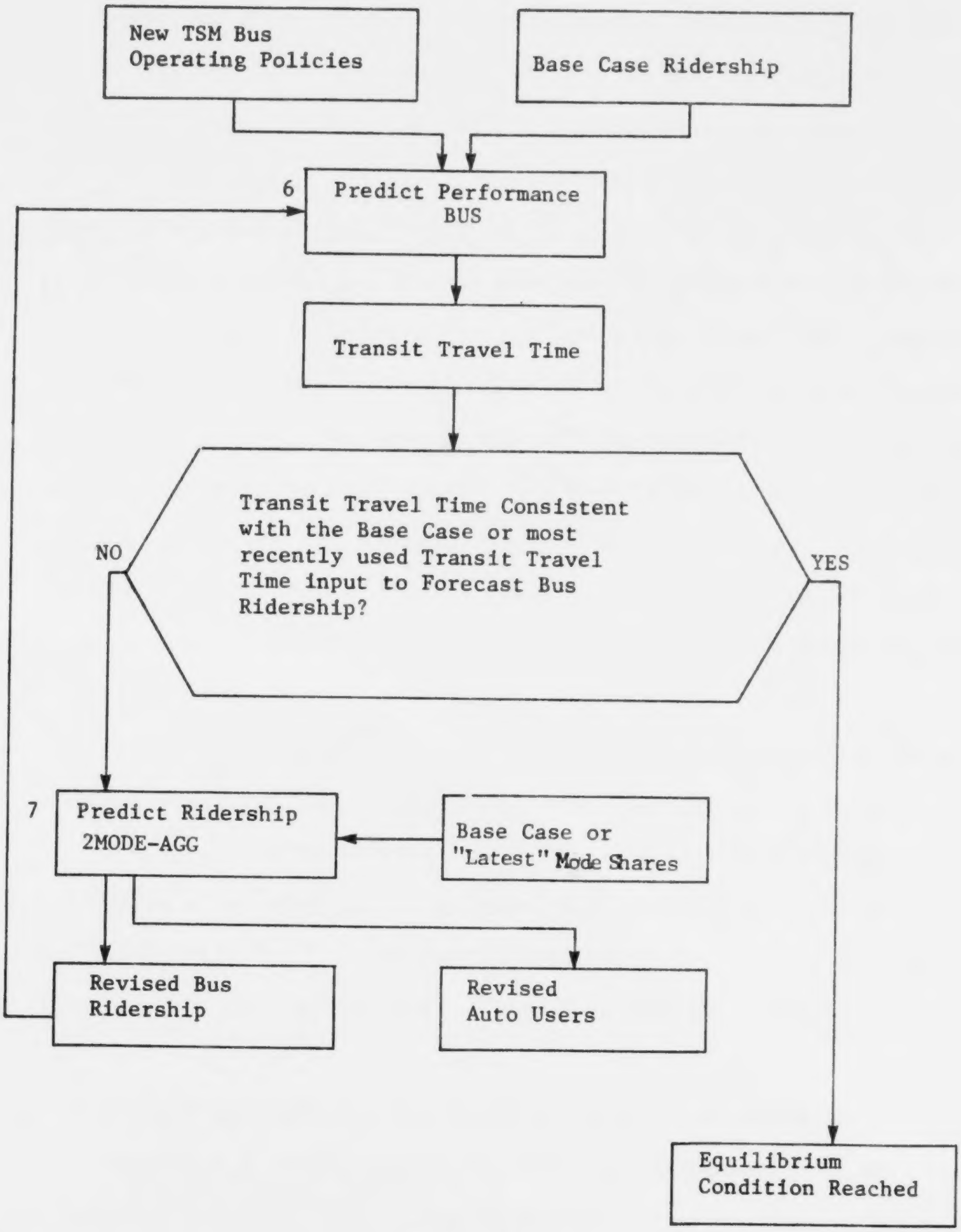
New TSM Bus Operating Policies
Base Case Ridership
6
Predict Performance BUS
Transit Travel Time
Transit Travel Time Consistent with the Base Case or most recently used Transit Travel Time input to Forecast Bus Ridership?
NO
YES
7
Predict Ridership 2MODE-AGG
Base Case or "Latest" Mode Shares
Revised Bus Ridership
Revised Auto Users
Equilibrium Condition Reached

FIGURE III- 14

Equilibrium Data Flows for Testing Effects of Transportation Measures

TABLE III-7

Equilibrium Transit Travel Times under Alternative Policies

	One-way travel time from zone centroid to in-bound terminus, minutes (percent change from base case)		
Origin Zone	Base Case	Signal Control	Signal Control + Preferential Lane
I	14.1 (-)	9.7 (-31.2%)	8.8 (-37.6%)
II	20.3 (-)	14.2 (-30.0%)	12.8 (-36.9%)
III	26.4 (-)	19.1 (-27.7%)	17.2 (-34.8%)

TABLE III-8

Equilibrim Transit Ridership under Alternative Policies

	One-way ridership (percent change from base case)		
Origin Zone	Base Case	Signal Control	Signal Control + Preferential Lane
I	1358 (-)	1420 (+4.6%)	1431 (+5.4%)
II	1048 (-)	1109 (+5.8%)	1125 (+7.3%)
III	361 (-)	422 (+16.9%)	438 (+21.3%)
TOTAL	2767 (-)	2951 (+6.6%)	2994 (+8.2%)

buses. Required inputs for the program include the route length (in miles), the headway, the average grade (important in hilly areas), the round-trip travel time, and the minimum layover time (usually set by agreement between the bus operator and the drivers). Program BUS provides the round-trip travel time estimate and the minimum layover is assumed to be ten minutes, consistent with the current policies of the bus operator. All other values required by ENERGY (with the exception of grade, which is assumed to be zero) are available from base data. The procedure is illustrated by the worksheets for the calculation of base case bus route energy consumption and fleet requirements shown in Figure III-15. Table III-9 shows the calculator output for each of the three runs. From these data, estimates of the per-hour operating cost of the route for the three scenarios (base, signal pre-emption, signal pre-emption with reserved lane) can be developed for evaluation purposes.

In Step 9, the impacts of the proposed bus priority strategies on the emissions of both buses and autos in the corridor are estimated. Program BUSPOL calculates the per-hour total emissions in grams of the bus fleet required to serve the route. The required inputs to the program are system (route) bus VMT per hour (10.6 miles round-trip x 20 runs per hour = 212 miles), and the average effective speed (available from the output of ENERGY). The program reports total hourly and per-mile emissions of CO, HC, NOx, particulates, and SOx in grams. The program is run three times with varying average effective speeds corresponding to the base case and the two alternative bus priority strategies. A sample run for the base case is illustrated by the worksheets in Figure III-16 and the calculator output is shown in Table III-10.

USER WORKSHEET - Energy Consumption on Bus Route

[ENERGY-1(A)]

Step	Procedure	Enter	Press	Print/Display
1.	Read card 1			
2.	Enter grade (0-5%)	Gr = 0	$\boxed{\text{A}}$	
3.	Read Card 2			
4.	Set print option if using printer		$\boxed{\text{2nd}}\boxed{\text{St flg}}$ $\boxed{4}$	
5.	Enter route characteristics			
	(1) Route length, round trip (mi)	d = 10.6	$\boxed{\text{STO}}\boxed{10}$	
	(2) Route travel time, round trip (min)(excluding layover	TT = 52.8	$\boxed{\text{STO}}\boxed{11}$	
	(3) Headway (min)	H = 3	$\boxed{\text{STO}}\boxed{12}$	
	(4) Minimum schedule slack time (min)	ST = 10	$\boxed{\text{STO}}\boxed{13}$	
6.	Compute fuel consumption		$\boxed{\text{B}}$	
	Read:			
	(1) effective operating speed (mph)			= 12.045
	(2) fuel consumption per mile		$\boxed{\text{RUN}}^*$	= 0.227
	(3) VMT/hr		$\boxed{\text{RUN}}^*$	= 212.0
	(4) fuel consumption per hour		$\boxed{\text{RUN}}^*$	= 48.182
7.	Compute schedule characteristics			
	(1) # vehicles required		$\boxed{\text{C}}$	= 21
	(2) Round trip travel time, including layover (min)		$\boxed{\text{RUN}}^*$	= 63.0

FIGURE III-15

Step	Procedure	Enter	Press	Print/Display
	(3) Layover time, round trip (min)		$\boxed{\text{RUN}}^*$	= 10.2
8.	To change any of the variables except grade, enter the new value(s) using the necessary part(s) of Step 5; repeat Steps 6 and 7. To change the grade, repeat the procedure from Step 1.			

---

*Not to be entered if print option is set.

TABLE III-9

Impacts Under Alternative Policies

(Example Calculator Output)

Impact	Base Case	Policy 1	Policy 2
Effective operating speed (MPH	12.045	16.649	18.488
Fuel Consumption per mile (gal/mi)	0.227	0.184	0.175
VMT/hr	212.000	212.000	212.000
Fuel consumption/hr (Gal/hr)	48.182	39.098	37.070
# vehicles required	21.000	17.000	15.000
Round trip route time (min)	63.000	51.000	45.000
Round trip layover time (min)	10.200	12.800	10.600

FIGURE III- 16

USER WORKSHEET - Bus Pollutant Emissions (BUSPOL-1)

Step	Procedure	Enter	Press	Print/Display
1	Read card (card 1 for TI 52)			
2	Set printing option if using printer		2nd St flg 4	
3	Load memory registers		2nd B'	
4	List memory contents (optional):			
	(1) Emission factor (particulates)	*(Note: This step may be omitted; factors are listed in Tables 1 and 2)*	2nd C'	= ________
	(2) Emission factor (SO_X)		RUN *	= ________
	(3) NO_X factors:			
	(a) ROAD		RUN *	= ________
	(b) IDLE		RUN *	= ________
	(c) URBAN		RUN *	= ________
	(d) emission factor		RUN *	= ________
	(4) HC factors:			
	(a) ROAD		RUN *	= ________
	(b) IDLE		RUN *	= ________
	(c) URBAN		RUN *	= ________
	(d) emission factor		RUN *	= ________
	(5) CO factors			
	(a) ROAD		RUN *	= ________
	(b) IDLE		RUN *	= ________
	(c) URBAN		RUN *	= ________
	(d) emission factor		RUN *	= ________

FIGURE III-16 (Cont.)

Step	Procedure	Enter	Press	Print/Display
5	Read card 2			
6	Enter system Vehicle Miles Traveled	VMT = 212	A	VMT
7	Enter effective speed (mph)	s = 12.04	B	s (printed only)
8	Compute CO emission (grams) - per vehicle-mile - total	(Note: Step 12 performs Steps 8-11 automatically)	 C RUN*	 = 22.08 = 4681.75
9	Compute HC emission (grams) - per vehicle-mile - total		 D RUN*	 = 4.46 = 945.34
10	Compute NO_x emission (grams) - per vehicle-mile - total		 E RUN*	 = 23.25 = 4928.65
11	Compute emission of (grams) - particulates per vehicle-mile - total particulates - SO_x per vehicle-mile - total SO_x		 2nd E' RUN* RUN* RUN*	 = 1.3 = 275.6 = 2.8 = 593.6
12	Perform Steps 8-11 automatically (TI 59 with printer only)		2nd A'	same as for Steps 8-11

FIGURE III- 16 (Cont.)

Step	Procedure	Enter	Press	Print/Display
13.	To vary VMT or speed, go to Steps 6 and 7 and proceed.			

Notes: *Not to be pressed if printing option is set (Step 2).
R/S on TI 59.

Steps 8-11 may be performed in any order.

TABLE III-10

Bus Emissions of Major Pollutants under Alternative Policies

(Calculator Printout)

	Base Case	Policy 1	Policy 2
System VMT	212.	(same)	(same)
Effective Speed	12.04	16.65	18.49
CO emission (gms)			
- per vehicle-mile	22.08	21.43	20.65
- total	4681.75	4542.82	4376.81
HC emissions (gms)			
- per vehicle-mile	4.46	4.08	3.92
- total	945.34	863.94	831.60
NOx emissions (gms)			
- per vehicle-mile	23.25	21.79	21.79
- total	4928.65	4618.71	4619.10
Particulates emissions			
- per vehicle-mile	1.30	1.30	1.30
- total	275.60	275.60	275.60
SOx emissions			
- per vehicle mile	3.80	2.80	2.80
- total	593.60	593.60	593.60

The auto emissions worksheets (4.1) were used to estimate the impact of the predicted increase in bus patronage on auto air pollutant emissions in the corridor.[1] The emissions model incorporated in the worksheets requires the number of auto work trip and total auto VMT for the base case and each alternative under study. Average travel speeds, the ambient temperature, and the analysis year determine the auto emissions rates for each scenario. Worksheet VI-A may be used to calculate the change in auto trip-making based on VMT estimates from 3MODE(VAN)-AGG and average trip length data. Alternatively, the total auto person trip volume reported by 2MODE-AGG (base case) and 3MODE(VAN)-AGG (alternative bus priority strategies) may be used directly to determine auto vehicle trips. The base case auto volume of 6120 (found by summing the market segment auto voluems in Figure III-5) predicted by 2MODE-AGG must be adjusted to reflect carpooling in the corridor. Using an auto occupancy value of 1.2 yields 5,100 vehicle round-trips per day, or 10,200 one-way trips. VMT is reported by 3MODE(VAN)-AGG for the base case and each alternative. Total base work VMT in the corridor is 72,030. The revised worktrip auto vehicle volume and total work trip VMT are estimated to be:

- Signal control - 9,890 one-way work trips; 70,100 VMT per day.
- Signal control and preferential lane - 9,750 one-way work trips; 69,620 VMT per day.

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[1] Because example applications of these worksheets also appear in Case Studies I and II, the completed worksheets have not been included in this Case Study.

An analysis year of 1982 is assumed for determining the work trip vehicle emissions impact. Non-work travel behavior is not expected to change significantly as a result of the bus priority measures. An ambient temperature of 50° is used, based on historical weather data. All subgroups will be analyzed together, using the VMT and trip values developed above.

Worksheet VI-B is used to determine the percentage of autos starting cold. Since parking duration data is not available for the corridor, Emissions Table D.1 provides the percentage of cold starts for 1982 work trips.

Worksheets VI-C and VI-D are executed three times, once for each scenario, including the base case, under analysis. Worksheet VI-E is completed for each bus priority alternative and is used to compare the performance of each measure relative to base conditions. The execution of Worksheets VI-C and VI-D will be described for the base case, and both executions of VI-E will be illustrated.

All subgroups are analyzed in one pass in both VI-C and VI-D. The percentage of cold starts for work trips is obtained from VI-B, and the number of trips from the information above. Start-up emissions factors for VI-C are obtained from Emissions Tables D.2, D.3, D.4, and D.6, using the analysis year of 1982, the ambient temperature of 50°, and the 90° cold-start percentage to enter the tables. No interpolation is necessary to obtain emission factors for this set of circumstances.

Emissions Table D.7 provides auto travel emission factors for Worksheet VI-D, using average speed and analysis year to determine the appropriate emissions rate. Based on several test speed runs on the arterial serving the study corridor, an average work trip speed of 25 mph is used. Once again, the emissions factors may be read directly, without interpolation. The execution of the worksheets for each alternative bus priority strategy is identical to the base case, with the only changes being the number of trips in VI-C and auto VMT in VI-D.[1]

Worksheet VI-E is used to calculate the percent change in vehicle emissions attributable to the proposed bus priority measures, which may then be used as input to a rollback or similar model to determine the change in ambient concentrations of pollutants in the atmosphere. Column 9 of Worksheet VI-E for the two alternatives indicates that signal control alone will lead to a 3 percent reduction in each pollutant, and that the addition of a preferential lane leads to an additional 1 percent decrease in pollutant emissions.

H. Interpretation of Results

Table III-11 summaries the estimated impacts of the proposed bus priority measures on auto and transit emissions in the study corridor. With the exception of NOx, the change in pollutant emissions for buses is insignificant in comparison to the predicted reduction in auto emissions. In most instances, from an areawide standpoint, transit emissions may be ignored when determining the air quality impact of tranportation measures, due to the much higher proportion of total emissions

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[1] Because existing auto volumes in the corridor are not high in relation to the capacity of the area's streets, the average speed of auto trips is not expected to change with the provision of an exclusive bus lane. In other applications, some increase in congestion might be expected which would have to be reflected in the emissions worksheets as a lower average speed.

VI-E. SUMMARY OF CHANGES IN EMISSIONS

Revised Alternative

Policy: Bus Priority Signal Control

Forecast Year: 1982

(1) Population Subgroup		Base Emissions			Revised Emissions			(8) Change in Total Emissions (Col. 4-Col. 7)	(9) Percent Change in Emissions (Col. 8/Col.4) x 100
		(2) Trip-Related (VI-C)[1]	(3) Travel (VI-D)	(4) Total (Col.2 + Col.3)	(5) Trip-Related (VI-C)	(6) Travel (VI-D)	(7) Total (Col.5+Col. 6)		
All	HC	186,660	115,248	301,908	180,987	112,160	293,147	- 8,761	- 2.9
	CO	2,029,800	1,750,329	3,780,129	1,968,110	1,703,430	3,671,540	-108,589	- 2.9
	NOx	35,700	151,263	186,963	34,615	147,210	181,825	- 5,138	- 2.7
	HC								
	CO								
	NOx								
	HC								
	CO								
	NOx								
	HC								
	CO								
	NO_x								

TOTALS

$\sum$ Sub-groups

	Total Base Emissions (grams)
HC	301,908
CO	3,780,129
NOx	186,963

$\sum$ Sub-groups

	Total Change in Emissions (grams)	Percent Change, Total Emissions
HC	- 8,761	-2.9
CO	-108,589	-2.9
NOx	- 5,138	-2.7

---

[1] Source Worksheets are indicated in parentheses where applicable

VI-E. SUMMARY OF CHANGES IN EMISSIONS

Revised Alternative

Policy: Bus Priority Signal Control & Pref. Lane

Forecast Year: 1982

(1) Population Subgroup		Base Emissions (2) Trip-Related (VI-C)[1]	(3) Travel (VI-D)	(4) Total (Col.2 + Col.3)	Revised Emissions (5) Trip-Related (VI-C)	(6) Travel (VI-D)	(7) Total (Col.5+Col.6)	(8) Change in Total Emissions (Col.4-Col.7)	(9) Percent Change in Emissions (Col.8/Col.4) x 100
All	HC	186,660	115,248	301,908	178,425	111,360	289,785	- 12,123	-4.0
	CO	2,029,800	1,750,329	3,780,129	1,940,250	1,691,280	3,631,530	-148,599	-3.9
	NOx	35,700	151,263	186,963	34,165	146,160	180,285	- 6,678	-3.6
	HC								
	CO								
	NOx								
	HC								
	CO								
	NOx								
	HC								
	CO								
	NOx								

TOTALS

$\sum$ Sub-groups

	Total Base Emissions (grams)
HC	301,908
CO	3,780,129
NOx	186,963

$\sum$ Sub-groups

	Total Change in Emissions (grams)	Percent Change, Total Emissions
HC	- 12,123	-4.0
CO	-148,599	-3.9
NOx	- 6,678	-3.6

---

[1] Source Worksheets are indicated in parentheses where applicable

TABLE III-11

Estimated Auto and Bus Emissions Impacts
(grams per day)

Pollutant	Change in Daily Emissions			
	Signal Control		Signal Control and Preferential Lane	
	Auto	Bus	Auto	Bus
HC	-8,761	-405	-12,123	-569
CO	-108,589	-695	-148,599	-1,525
NOx	-5,138	-1,550	-6,678	-1,550

related to auto travel. However, as the air quality impact estimates for this example illustrate, if nitrogen oxide levels are of major concern, or if changes in ozone concentration are to be estimated based on the change in total HC and NOx emissions, the impact of the proposed measures on bus NOx emissions should be considered.

Although modest decreases in total vehicle emissions are predicted by the analysis, the estimated impact is large enough that beneficial air quality impacts may be attributed to either of the bus priority strategies with a high level of confidence. Further analysis of the two proposed alternatives might focus on a more in-depth assessment of the transit operations and traffic flow implications of the measures. A more detailed analysis of the bus route using either BUS, with a greater number of stations and intersections; or a computerized analysis tool such as TRANSYT-6C would be justified in order to assess fleet requirements and traffic flow changes. The ultimate choice between the two alternative bus priority strategies will depend on the more in-depth assessment of the performance of each which could be provided by a more detailed operational analysis.

CASE STUDY IV

AREAWIDE ASSESSMENT OF TRANSPORTATION MEASURES

CASE STUDY IV: AREAWIDE ASSESSMENT OF TRANSPORTATION MEASURES

A. Problem Statement

An urban area currently not attaining minimum health standards for CO and ozone concentrations is beginning the process of analyzing transportation/air quality measures for inclusion in its 1982 SIP revision. Through its involvement in planning studies for a number of major transit development alternatives, the area's MPO has developed an extensive and up-to-date UTPS-based model system, including highway and transit networks and zonal population, socioeconomic and employment projections at five-year intervals to the year 2000. However, the MPO has found the travel demand models incorporated in their model system expensive to use and insensitive to the types of short-range transportation measures commonly included in air quality improvement strategies. The MPO wishes to develop a capability to systematically analyze the air quality, fuel consumption and modal choice impact of a range of measures it is considering for inclusion in its SIP revision.

B. Proposed Transportation Measures

Because of the area's non-attainment status, the MPO is required to consider the entire range of reasonably available control measures. Illustrative of the types of action the MPO hopes to evaluate are the following four measures:

- Increase service frequencies on all CBD-bound transit routes during the peak hour;
- Initiate carpool matching and promotional programs at all major employers (i.e., firms with over 50 employees);
- Restrict the number of employer-provided parking spaces used by single-occupant autos;
- Combine the restriction of single-occupant auto parking spaces with the promotion of carpooling.

Through such measures, the MPO hopes to reduce the use of the single-occupant auto, while increasing the utilization of transit and carpooling. Energy conservation as well as environmental protection benefits are expected to accrue if a successful program of transportation control measures can be devised.

C. Selection of Analysis Method

Because the urban area has an up-to-date UTPS-based model system, SRGP (2.3.2)[1] can be implemented relatively inexpensively and can provide a flexible and inexpensive tool for analyzing a large number of alternative transportation measures at the urban area level. SRGP is more desirable in this instance than the available manual techniques because of its ability to quickly analyze a large number of strategies. At the same time, the computational power of the computer-based method will allow a high degree of accuracy and the ability to isolate the effects of alternative policies on special groups within the urban area. Therefore, SRGP has been selected for application to the urban area's SIP planning process.

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[1] The section numbers following specified analysis methods refer to the location of their description in Volume I.

D. Input Data Development

A work program for setting up SRGP for use in a given urban area was described in Volume I. The basic steps in the work plan involve:

- developing base year data files;
- adjusting model coefficients (model calibration);
- updating base year data to analysis year conditions.

SRGP requires three types of base data: a sample of households, transportation levels of service for peak and off-peak trips, and land use characteristics.

The primary source of household information available for the case study urban area is an areawide home interview survey (HIS) conducted in 1971. Level-of-service data were available in the form of standard UTPS networks representing peak and off-peak conditions in 1975. Zonal population, employment, and land use data were available from a study conducted in 1970 which developed forecasts of these data in five-year increments to the year 2000. The travel behavior models within SRGP are calibrated on base year data from 1971 assuming that no major land use, population, and employment pattern changes had occurred since the 1970 study.

The sequence of data processing steps required to develop the household, level-of-service, and zonal input files is shown in Figure IV-1. The first step was to reduce the household file from 15,000 (the sample size of the HIS) to 2,506 households in order to minimize the data processing costs of subsequent steps, while maintaining an adequate sample size for analysis purposes. The size and composition of the household sample used in SRGP depends on the desired accuracy of the impact predictions generated, the degree to which the impacts on specific groups

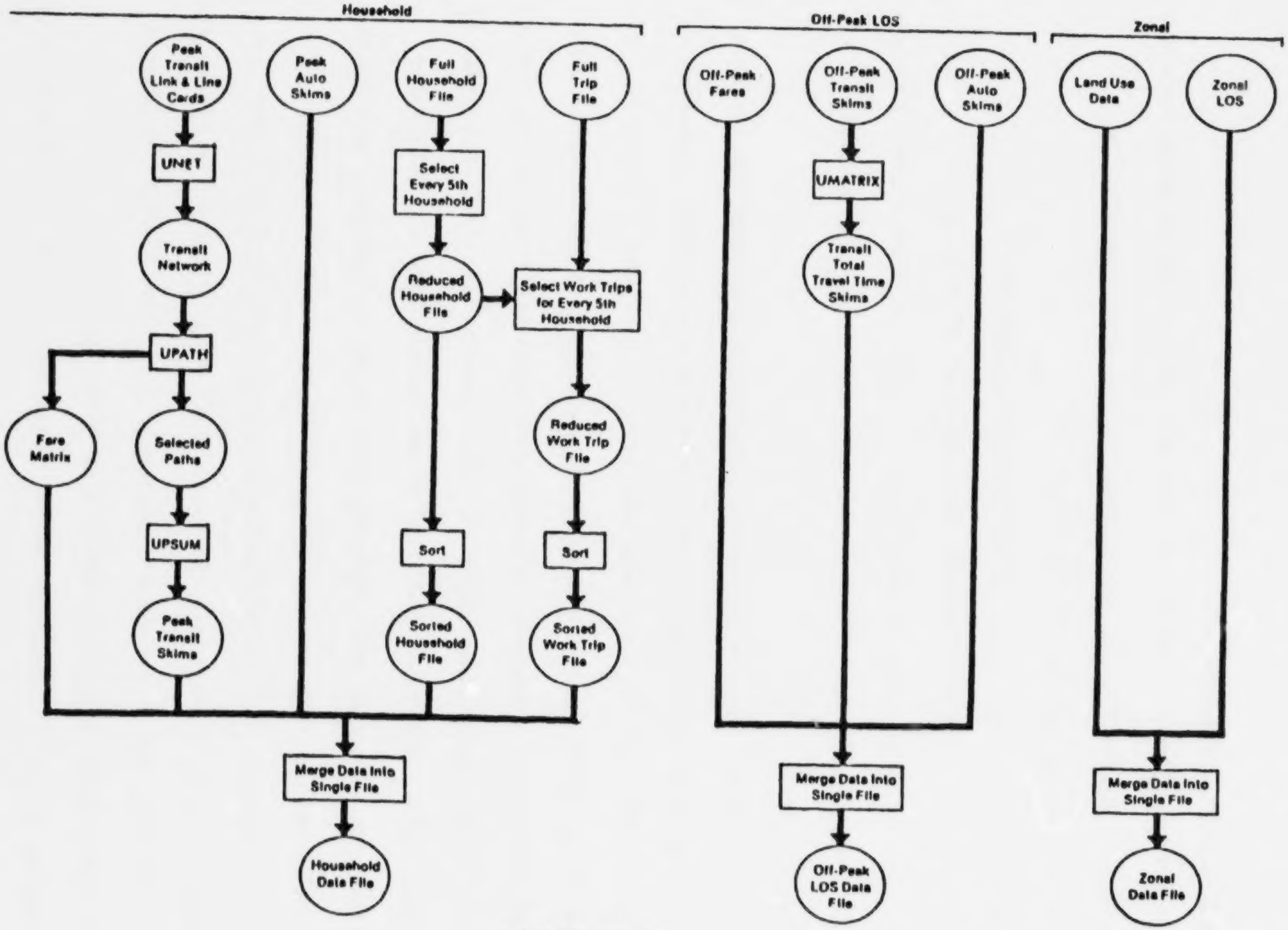

FIGURE IV-1

SRGP Data Preparation Steps

are of interest, and the budget constraints placed on data processing. The trip file was also shortened to include only work trips associated with the reduced household file.

Both the household and trip files were sorted by ascending home zone number and, within a given home zone, by ascending household identification number. The trip file was further sorted by ascending person number within each household.

Peak period transit level-of-service data in the form of skimmed trees was obtained from basic transit network data using standard UTPS software; skimmed trees for auto were already available. At this point, a FORTRAN program was developed to merge these data into a single file in the appropriate format for input to SRGP.

Developing the off-peak level-of-service file was straightforward. Skims of 1975 off-peak networks for both auto and transit were already available. For transit, UMATRIX was used to combine IVTT and OVTT to form the required total travel time variable. The resulting transit skims were then combined with the auto skims and transit fare matrix into a single file using a FORTRAN program.

The zonal data file development was also straightforward. A simple FORTRAN program was used to merge the 1970 zonal population, employment, and land-use data with the required zonal transportation level-of-service variables.

Once the base-year data were organzied into the required input files, the SRGP model system was calibrated to the analysis area by adjusting the alternative specific constant terms of each component model iteratively until the regional travel behavior predicted by the model system matched that

TABLE IV-1

Estimated versus Adjusted Values of Alternative Specific Constant Terms - Case Study IV

Model/Constant Term	Estimated Value	Adjusted Value
Worker Household Auto Ownership		
1 Auto Constant	4.989	6.295
2 Auto Constant	5.689	7.615
Non-Worker Household Auto Ownership		
1 Auto Constant	-.8695	-.9092
2 Auto Constant	-8.357	-8.6119
Work Trip Mode Choice		
Drive Alone Constant	-4.697	-1.867
Shared Ride Constant	-3.658	-3.657
Shopping Trip Destination/Mode Choice		
Auto Constant	-1.080	1.0906
Soc/Rec Trip Destination/Mode Chocie		
Auto Constant	1.844	4.714
Shopping Trip Generation		
Shop Expansion Factor	1.0	.9496
Soc/Rec Trip Generation		
Soc/Rec Expansion Factor	1.0	1.6106

observed for the base year. For this purpose, observed travel data were taken from trip summaries and other tabulations available from the home interview survey. Both the original and adjusted values for the constant terms are shown in Table IV-1 for all of the SRGP models.

E. Description of Model Application and Impact Assessment

Data Updating

To analyze the impacts of implementing selected transportation policies in future analysis years, it was necessary to use input data that reflected conditions in these years. While the available level-of-service data already satisfied this requirement, the household data file and certain elements of the land use data file required updating to reflect future conditions.

The household data were updated using a procedure in which household expansion factors are modified to represent expected changes in the distribution of selected population characterisitcs within the urban area.[1] Selection of the actual household characteristics used in updating was constrained by the availability of projections for these characteristics in future years. For the example urban area, projections of employment and population were available in five-year increments for each of 34 geographic divisions within the metropolitan area. Areawide household income projections were also available in five-year increments for the region. Employment figures, though, were only available from 1970 data and projections for the year 2000. The values for these variables in other years were obtained by linear interpolation between the 1970 and 2000 levels.

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[1] The details of this procedure are given in Cambridge Systematics, Urban Transportation Energy Conservation, Vol. II: Analytical Procedures for Estimating Changes in Travel Demand and Fuel Consumption, prepared for U.S. Department of Energy, September, 1978.

As an illustration of the household updating process, consider an upper income household living in a suburban area. In the year for which the household file is representative (the year of the HIS in this case), households with these characteristics represented 20 percent of the urban area's population. In the analysis year, however, such households are projected to represent 40 percent of the urban area population. To update the household file to the analysis year, the household expansion factor for all upper income households in suburban areas would be increased by a factor given by:

$$\begin{aligned} \text{Factor} &= \frac{\text{Analysis Year Fraction}}{\text{Base Year Fraction}} \\ &= \frac{.40}{.20} \\ &= 2.0 \end{aligned}$$

The expansion factor for other households would similarly be reduced to reflect their lower representation in the total population.

Zonal data must also be updated to reflect population, employment, and land use changes. The five-year projections of zonal characteristics were used to update key zonal variables for the example urban area, using multiplicative factors similar to those used for the household file. Household data files and zonal data files were developed for each of the analysis years of interest using these updating techniques. Level-of-service changes in the analysis years reflecting the policy measures to be evaluated are communicated to SRGP by means of various input parameter options. The following sections illustrate how some of these options are executed for analysis purposes.

F. Representing Transportation Measures in the Model System

Once the necessary household, zonal, and level-of-service data (reflecting changes in the quality of service caused by general population growth and other trends) has been assembled for the analysis year and used to update the SRGP input files, policy options may be evaluated for the analysis year. Example applications indicating the statements required to analyze the following policy measures are illustrated below:

- Increase frequency of transit service to the CBD during peak periods;
- Initiate carpool matching and promotional programs at all employers with 50 or more employees;
- Restrict the number of employer-provided parking spaces used by single-occupant vehicles;
- Combine the parking restrictions above with employer-based carpool and vanpool promotion and matching.

1. Increase Frequency of Transit Service to CBD - With this measure, headways on all transit routes to the CBD are to be reduced by 50 percent during the peak period. Because this measure can be expressed directly in terms of changes in levels of service, its representation is fairly straightforward. The first step in translating this measure into model system parameters is to identify those individuals who would be affected by such a measure. Assuming that measures applied only during peak periods will influence work travel only, this measure would affect all

workers with employment locations in the CBD. This measure then must be transformed into changes in the appropriate model variables. In this case, doubling peak period transit frequency would be represented by a 50 percent decrease in the transit headway variable for the work trip mode choice model.

For this measure, only four statements are required to represent the level-of-service changes in SRGP. First, it is necessary to establish a correspondence between the traffic zone system used in developing the basic input data files for SRGP, and the geographic areas to which the proposed measure applies. This is accomplished by identifying two districts (the CBD and the rest of the urban area) and then defining the districts with the appropriate traffic zone numbers using the following three statements:

```
&PARAM DIST=2 &END
&EQUIV DIST=1, Z=<range of CBD zone numbers> &END
&EQUIV DIST=2, Z=<range of non-CBD zone numbers> &END
```

With these two areas defined, the only other statement necessary is that which actually indicates the variable to modify, how to modify it, and who is affected by this change. For this measure, the statement would be:

```
&WORK O=1, 2, D=1, FAC(7)=.5 &END
```

The statement specifies that this "update" is applied to work trips (&WORK) from origin districts 1 and 2 (O=1, 2), which encompases the entire urban area, to destination district 1 (D=1), which is the CBD. The update itself (FAC(7)=0.5) specifies that the seventh field in the work trip data segment (e.g., - transit headway) is to be multipled by 0.5.

When SRGP is run with these options set, the model system processes each household as it would in the base case with revisions reflecting the data update to the analysis year, except that whenever a work trip destined to the CBD is encountered, transit headway is halved, and new mode choice probabilities are calculated using this revised headway.

Once processing of the household data file is completed, various statistics on travel-related impacts accumulated throughout the run are printed, both as expanded totals for the entire urban area and as household averages. In addition, if a file of base case statistics for the analysis year had been created in an earlier run, this information could now be read and compared with travel-related impacts predicted for this measure. The results of this comparison then would be printed in the form of percentage changes from base case statistics.

Table VI-2 presents selected impacts predicted for increasing transit frequencies in terms of percentage changes from the base case. Also shown are expanded areawide totals and average work trip values for the base case. Note that while this measure affects CBD work trips only, the impacts are presented for the entire urban area. The percentage changes given in Table IV-2, then, represent the changes associated with CBD work travel relative to all work travel. Since in this example work trips to the CBD account for 10 percent of all work trips, the corresponding percentage changes for CBD workers alone are about ten times as great as those given in Table IV-2. On an areawide basis, the impact of this measure on auto travel is relatively small--VMT decreases by only .4 percent. The corresponding decreases in emissions range from .3 percent for NOx to .5 percent for CO.

TABLE IV-2

Changes in Travel Behavior and Travel-Related Impacts

IMPACT (% Change from Base)

TRANSPORTATION CONTROL MEASURES	WORK TRIP MODE SHARES				WORK TRIP VMT	WORK TRIP FUEL CONSUMPTION	WORK TRIP AUTO EMISSIONS kg/day		
	Drive Alone	Shared Ride	Transit	Vanpool	mi/day	gal/day	HC	CO	NO_x
Areawide Base (Totals)	306,000	76,200	10,800	0	5,030,000	413,000	50,900	727,000	19,600
Areawide Base (Average Round Trip)	0.78	0.19	0.03	-	12.99	1.06	0.12	1.17	0.03
Headways Reduced by 50% (CBD Only)	-.5	-.8	3.6	0	-.4	-.4	-.4	-.5	-.3

2. Employer-based Carpool Matching and Promotion - With this measure, employers in the urban area are assumed to initiate promotional campaigns encouraging carpooling and to provide carpool matching assistance for their employees. Since carpooling incentives such as these are feasible only for organizations with a relatively large number of employees, the most logical criterion for determining the availability of such incentives to an individual worker is employer size. However, this information was not available for individual workers in the urban area under study. Instead, employer size distribution data on a zonal or district level was used to determine for each traffic zone the fraction of workers in a given zone employed by companies of a specified size or larger.[1]

To forecast the impacts of carpool incentives, a random number (between 0 and 1) is generated for each work trip to determine whether or not that worker will benefit from the particular carpool incentives being modelled. If the number generated is less than or equal to the fraction of workers employed by large companies in the worker's work zone, the carpool incentives are available to that worker; if the number is greater, the worker does not benefit from the carpool incentives.

Because employer-based incentive programs such as these cannot be easily reduced to time and cost terms, SRGP incorporates a specific variable to represent the existence of an employer-based carpool promotion program. For workers exposed to the promotion campaign, the variable takes on the value "1," for others, "0." This variable is then incorporated into the utility function for the shared ride mode for work trips.

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[1] In this case, incentive programs at employers with at least 50 employees were compared with similar programs only at firms employing 250 or more.

Since this measure is essentially areawide in scope, no district definitions or zonal equivalences are required; its representation is communicated to SRGP by means of a single control card:

```
&POOLS ZCPOOL=20, PMATCH=.287 &END
```

The keyword ZCPOOL=20 indicates that this run will include employer-based incentives, and that the required employer size data are located in field 20 on the zonal data file. PMATCH=.287 specifies that these incentives will include matching and promotion, which are represented by adding .287, the estimated coefficient value for the carpool incentive variable discussed earlier, to the shared-ride utility function for those workers employed by large employers. Note that in addition to matching and promotional incentives, it is also possible to represent any employer-based travel time or cost-related measures such as preferential carpool parking, differential parking charges, etc.

The results of this measure, expressed in percentage changes from the base case, are shown in Table IV-3. As shown, the implementation of carpool matching assistance and promotional programs by organizations with 50 or more employees results in a decrease in areawide work trip VMT of 1.4 percent and decreases in auto emissions of 1.3 percent for hydrocarbons, 1.1 percent for carbon monoxide, and 1.5 percent for nitrogen oxides. When such carpool incentives are offered only by firms with 250 or more employees, the resulting decrease in VMT is .8 percent, with decreases

TABLE IV-3

Percent Changes in Travel Behavior and Travel-Related Impacts of Ridesharing Promotion

IMPACT (Percent Change from Base)

TRANSPORTATION CONTROL MEASURE	WORK TRIP MODE SHARES				WORK TRIP VMT (mi/day)	WORK TRIP FUEL CON-SUMPTION (gal/day)	WORK TRIP AUTO EMISSIONS (kg/day)		
	Drive Alone	Shared Ride	Transit	Vanpool			HC	CO	NOx
Carpool Program (50 Employees)	-2.9	+13.0	-10.1	-	-1.4	-1.2	-1.3	-1.1	-1.5
Carpool Program (250 Employees)	-1.5	+ 6.8	- 6.6	-	-0.8	-0.6	-0.7	-0.6	-0.8

in auto emissions ranging from .6 to .8 percent. The difference between these results (expressed on an areawide basis) is due to the difference in the number of employees affected. When 50 employees is used as the lower bound for employer size, approximately 60 percent of the work force is reached by the measure; when a size of 250 employees is used, only 30 percent of the work force is reached.

3. Restrictions on Employer-Provided Parking - The measure considered here is also employer based, but is defined as a disincentive to single-occupant auto use rather than an incentive for carpooling. This measure is a parking supply restriction which limits the number of parking spaces that an employer can provide to single-occupant vehicles by setting a maximum value based on the number of employees. This measure is assumed to apply only to organizations, either public or private, employing at least 250 people since the practical problems associated with implementing and enforcing such a measure for a large number of small firms, many of which may use facilities jointly with other firms (if indeed they provide parking at all), would be extremely difficult. In addition, firms located in the CBD are assumed to be unaffected since much of the parking there is in commercial facilities rather than employer-provided. It also is assumed that the necessary restrictions could be applied to prohibit the use of alternative on-street parking nearby. A contingency measure such as this normally would not be included in a SIP. Its presentation here, then, is for illustrative purposes.

In examining parking supply restrictions, the most appropriate analysis approach depends on the nature and severity of the restriction. In those cases where supply restrictions affect only excess capacity (e.g., when the number of parking spaces available after the restriction is still greater than or equal to the number of spaces utilized before the restriction), the immediate impact would be increased search and walk time--for those individuals forced to use more inconveniently located spaces--and possibly increased parking costs if those spaces affected by the restriction are free or relatively inexpensive. This type of restriction, then, would be represented straightforwardly in terms of changes in travel time and cost. The magnitudes of these changes would depend on the characteristics of those spaces affected by the restriction.

On the other hand, if restrictions are to be imposed which reduce the total supply of parking in an area below the level that is currently used, an iterative forecasting procedure is required to calculate supply/demand equilibrium. In such a procedure SRGP would proceed through the household sample once, and expand the results to estimate the number of auto trips to the area affected by the supply restriction. From this, the required number of parking spaces could be calculated and compared with the number of spaces that would be available with the parking restriction in effect to determine the extent to which auto travel must be reduced. Then, a "shadow price" or penalty price (in terms of excess travel time) for utilizing a constrained resource would be estimated and applied in the appropriate utility functions of the demand models, and SRGP would be rerun to produce revised travel patterns. This sequence would be repeated, altering the shadow price until the demand for parking falls within the limits of the total available parking supply.

TABLE IV-4

Changes in Travel Behavior and Travel-Related Impacts (A)

IMPACT (% Change from Base)

TRANSPORTATION CONTROL MEASURES	WORK TRIP MODE SHARES				WORK TRIP VMT	WORK TRIP FUEL CONSUMPTION	WORK TRIP AUTO EMISSIONS (kg/day)		
	Drive Alone	Shared Ride	Transit	Vanpool	(mi/day)	(gal/day)	HC	CO	NOx
Areawide Base (Average/Round Trip)	0.78	0.19	0.03	-	12.99	1.06	0.12	1.17	0.03
Restrictions on Employer-Provided Parking:									
-Ratio of drive-alone spaces/employees; 0.3 at large employers	-7.1	26.6	9.2	-	-4.1	-3.6	-3.8	-3.7	-4.5
-Ratio of drive-alone spaces/employees; 0.4 at large employers	-11.0	41.1	13.8	-	-6.3	-5.6	-5.8	-5.7	-6.9

The measure considered here was defined as a maximum value for the ratio of the number of parking spaces provided by an employer for use by single-occupant vehicles, divided by the number of employees. Two values for this ratio were examined: 0.4 and 0.5. Since the existing value was 0.76, both levels result in reductions in parking supply below the level currently utilized, and therefore the second analysis approach described above was used in each case. The shadow price necessary to achieve the 0.5 value was an increase in walk time of 35 minutes. To achieve the 0.4 value, an increase of 50 minutes was required. The values of these shadow prices reflect the severity of restriction represented by the imposition of parking space quotas.[1]

The results of these measures are presented in Table IV-4 as percentage changes relative to areawide work travel characterisitcs. Because these measures are primarily disincentives to driving alone, both the shared ride and transit mode shares increase. However, because transit is not available to all workers, whereas the shared ride alternative is, the percentage increase in shared-ride on an areawide basis (ranging from 26.6 percent to 41.1 percent) is greater than that for transit (9.2 percent to 13.8 percent). These changes in travel behavior translate into reductions in areawide work trip VMT ranging from 4.1 percent to 6.3 percent, and reductions in work trip auto emissions ranging from 3.8 percent to 6.9 percent. For evaluation purposes, these reductions must be compared with the severity of restriction represented by the shadow price values required to reduce drive-alone travel to levels matching the availability of parking spaces.

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[1] The size of the shadow price gives insight into the reasons behind the unpopularity of severe parking supply restrictions.

4. Combined Measures: Employer-Sponsored Carpool/Vanpool Programs with Restrictions on Employer-Provided Spaces - The purpose of examining this combination of individual measures is to explore the synergistic effects of combining actions that are essentially disincentives for driving alone with measures designed as incentives for using modes other than the single-occupant auto. The employer-based parking restrictions and carpool programs are identical to the individual measures described in the previous two examples. Employer-based vanpool programs offer an additional ride-sharing alternative to the single-occupant auto. As in the case of employer-based carpooling incentives, vanpooling programs are most frequently organized by larger employers; therefore, the same employer size criterion for determining the availability of vanpooling is used. Further, experience has shown that commuters choosing vanpooling as their mode to work typically have relatively long trip lengths. Therefore, another constraint imposed on the availability of vanpooling as an alternative is trip length (a ten-mile, one-way trip length is used as a lower bound). Employer-sponsored vanpool programs are represented in the demand model system by adding a new mode to the set of available modes for the work trip for those commuters who are employed by large organizations and have long work trips.[1]

The results of these measures are presented in Table IV-5 for the incentives and disincentives implemented individually as well as in combination. As shown, this particular combination of measures is about

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[1] More detailed documentation of the vanpool option is presented in Cambridge Systematics, Urban Transportation Energy Conservation, Vol. II: Analytical Procedures for Estimating Changes in Travel Demand and Fuel Consumption, prepared for US Department of Energy, Sept. 1978.

TABLE IV-5

Changes in Travel Behavior and Travel-Related Impacts (B)

IMPACT (% Change from Base)

TRANSPORTATION CONTROL MEASURES	WORK TRIP MODE SHARES				WORK TRIP VMT	WORK TRIP FUEL CON-SUMPTION	WORK TRIP AUTO EMISSIONS kg/day		
	Drive Alone	Shared Ride	Transit	Vanpool	mi/day	gal/day	HC	CO	NOx
Areawide Base (Average/Round Trip)	9.78	0.19	0.03	-	12.99	1.06	0.12	1.17	0.03
Carpool/Vanpool Program (250 employees)	-2.8	4.0	-3.6	(.015)*	-3.7	-2.6	-3.0	-2.9	-3.5
Restrictions on Employer-Provided Parking:									
-Ratio of drive-alone spaces/employees; 0.5 at large employers	-7.1	26.6	9.2	-	-4.1	-3.6	-3.8	-3.7	-4.5
-Ratio of drive-alone spaces/employees; 0.4 at large employers	-11.0	41.1	13.8	-	-6.3	-5.6	-5.8	-5.7	-6.9
Carpool/Vanpool Program plus Restrict Employer-Provided Spaces to High Occupancy Vehicles; Ratio of drive-alone spaces/Employees:									
0.5	-10.8	31.4	3.8	(.02)*	-8.9	-7.0	-7.6	-7.4	-9.0
0.4	-14.6	44.9	7.3	(.02)*	-11.3	-9.0	-9.7	-9.5	-11.5

* Represents new share rather than percentage change.

14 percent more effective in terms of VMT reduction than the sum of the two component measures taken individually. (The corresponding increase in effectiveness in terms of work trip auto emissions reductions ranges from 10 percent to 13 percent.) A convenient way to illustrate the synergistic effects of combined measures is to graph the single and combined measure impacts as shown in Figure IV-2. The lower curve represents the effectiveness of the supply restrictions alone; the middle curve represents the summed effect of the supply restriction and employer-sponsored carpool and vanpool programs taken individually. The upper curve represents the effectiveness of these measures implemented in combination. The shaded area, then, represents the increased effectiveness attributable to the synergistic effect of the combined implementation of these measures.

G. Interpretation of Results

Organizing the SRGP output into tables and graphs such as those presented in the previous section can be a significant aid to analyzing and interpreting the predicted impacts of proposed measures. Of particular value is the comparison of the single and combined effects of a number of measures. In many cases, the synergistic effect of the combined implementation of carpooling incentives and auto use disincentives may lead to a cost-effective transportation control strategy, where single actions cannot be justified based on their benefits and costs. Because none of the reasonably available control measures alone is likely to lead to emissions reductions large enough to bring an urban area with serious

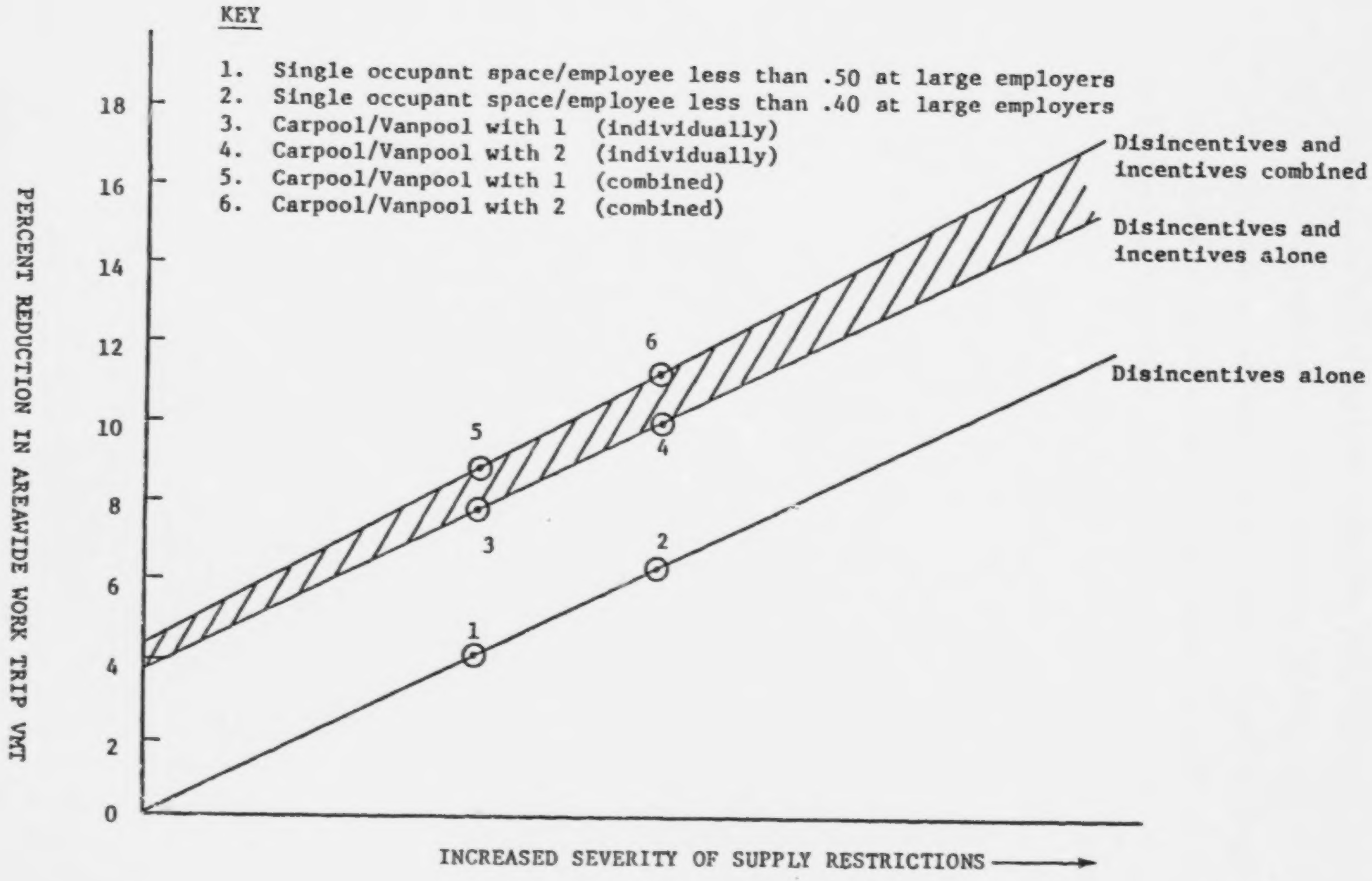


FIGURE IV-2

Effectiveness of Combining Incentive and Disincentive Measures air quality problems into conformance with the health standards for air pollutant concentrations, designing effective packages of measures will be an important aspect of air quality/transportation planning. The technique of comparing single and multiple measures can aid in the development of a cost-effective package of measures which can lead to significant improvements in air quality.

CASE STUDY V

ANALYZING A PROPOSED BUSWAY NETWORK

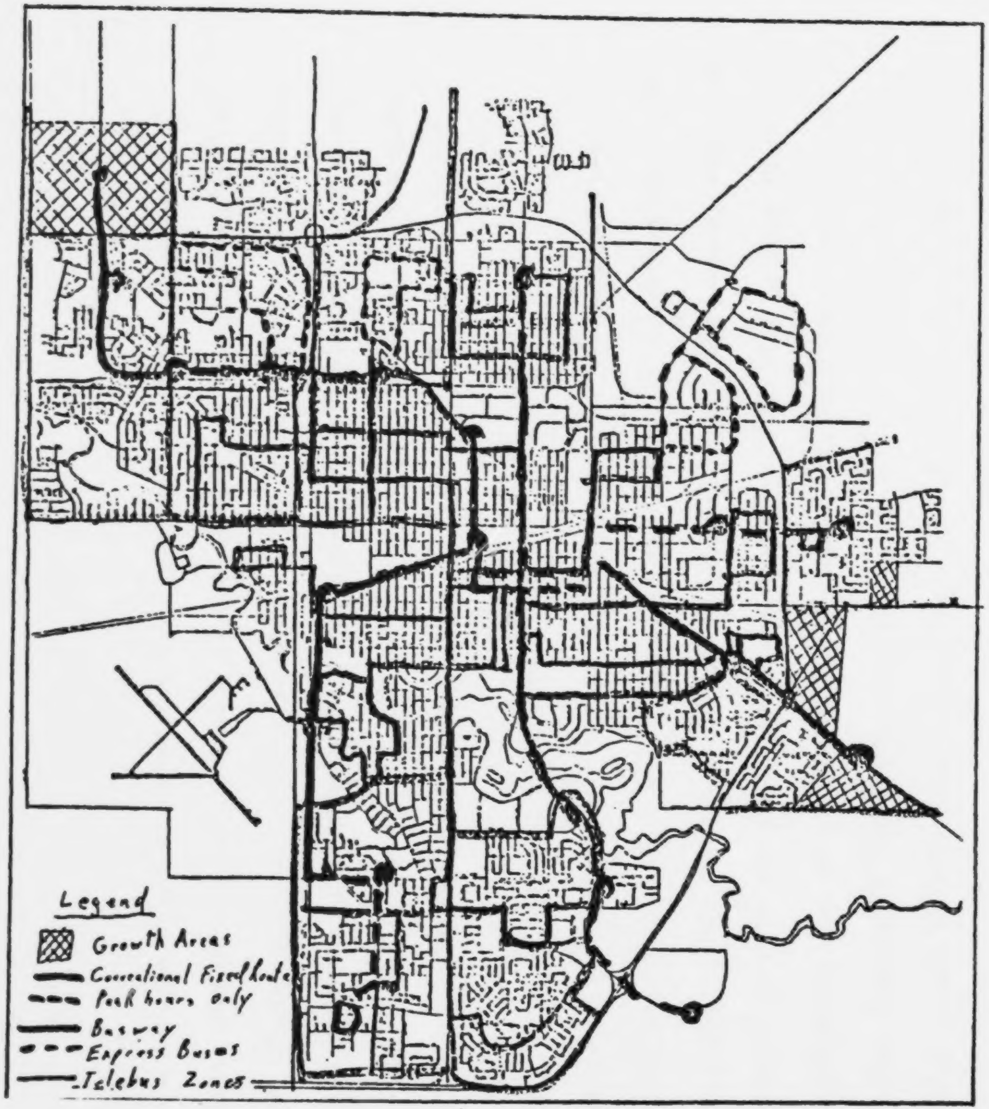
CASE STUDY V: ANALYZING A PROPOSED BUSWAY NETWORK

A. Problem Statement

A small but densely settled city with relatively poor existing transit service is considering a number of major public transit improvement projects. Among the proposed new systems is a network of busways providing line-haul express service to the CBD, supported by improved conventional fixed-route bus service and demand responsive feeder bus service in residential areas. In order to choose between the proposed busway option and the other possible alternatives, the local planning agency and decision makers need to know what the transit ridership, VMT, and air pollution impacts of the proposed system will be. The urban area has implemented the standard UTPS model system for use in analyzing its transportation system, but has found the standard aggregate passenger demand models difficult and expensive to use. Because a large number of alternative solutions to the area's public transportation needs (including the proposed busway) are under initial consideration, a fast and inexpensive method of screening the range of alternatives is desired, so that detailed analyses can be conducted for only the most promising alternatives.

B. Proposed Transportation Measures

The proposed network of busways and supporting bus services are shown in Figure V-1. Three busways, serving the northwest, southeast and southwest travel corridors in the city would be built under this plan. Several express bus routes would use each of the busways and three express routes would use the existing street network. A number of local fixed-route



• Express Bus Stops/Stations

FIGURE V-1

Busway Network

TRANSIT STRATEGY OPTION

BUSWAY NETWORK

TRANSIT POLICY OPTION

Moderate Service Level

LINE HAUL - *Express Buses on/off Busway*
- *Conventional Fixed Route*

COLLECTION (Residential)

.PEAK HOURS - *"Rationalized" Telebus*

OFF-PEAK - *Telebus*

DISTRIBUTION - *Overlapping Fixed Routes*

(CBD, Activity Centers)

	FEEDER	FIXED ROUTE	EXPRESS/ BUSWAY
STATION SPACING			
AVERAGE CBD	----	*550 ft.*	*550 ft.*
AVERAGE SUBURBAN	*on demand*	*800 ft.*	*4000 ft.*
SERVICE HOURS			
PEAK	*5 hrs*	*5 hrs*	*5 hrs*
OFF-PEAK	*13 hrs*	*13.5 hrs*	*-/7 hrs*
SERVICE FREQUENCY			
PEAK	*12 min*	*12 min*	*30/12 min*
OFF-PEAK	*20 min*	*20 min*	*-/20 min*
NIGHT	*30 min*	*30 min*	----
FARES			
ADULT	*45¢**	*30¢*	*45¢**

** INCLUDES FREE TRANSFER TO OTHER SERVICES*

services from the existing transit system would remain in service, supplemented by Dial-a-Ride services (termed "Telebus") in outlying suburban residential areas. Coordinated transfers are planned between nearly all services.

In order to maximize the usage of the routes using the new busways, a package of auto disincentives is planned for implementation when busway construction is completed. Increased parking costs for CBD auto commuters, and a limit on the construction of new parking spaces in the CBD are the major features of the auto disincentive plan.

The busway plan, if implemented, could be completed by the mid 1980's. An analysis year of 1987 was chosen to coincide with the deadline for the attainment of the health standards for air pollution since the expansion of bus service in the city is anticipated to have a significant impact on air quality, particularly in the city's downtown area.

C. Selection of Analysis Technique

The important factors affecting the choice of the analysis technique to use in evaluating the busway alternative (and the other proposed transit development projects) are:

- The budget available for the analysis of the proposals is limited. At this early stage, when a range of alternatives is being explored, a detailed analysis of all of the proposals using the full UTPS model system is not possible.
- A large number of alternatives must receive an initial screening. These alternatives represent a significant change in existing conditions and will lead to the provision of completely new services in many areas of the city. Because the level-of-service changes associated with the proposed new transit systems are not incremental, the manual and calculator pivot-point demand analysis methods are not appropriate.

- Many of the proposals involve new construction, so that the changes being evaluated are facility- rather than service-oriented. This fact, combined with the limited budget available for implementing new computer analysis capabilities and the lack of a recent home interview survey, argues against the use of SRGP, which is more applicable to policy measures (such as carpooling programs and parking management strategies).

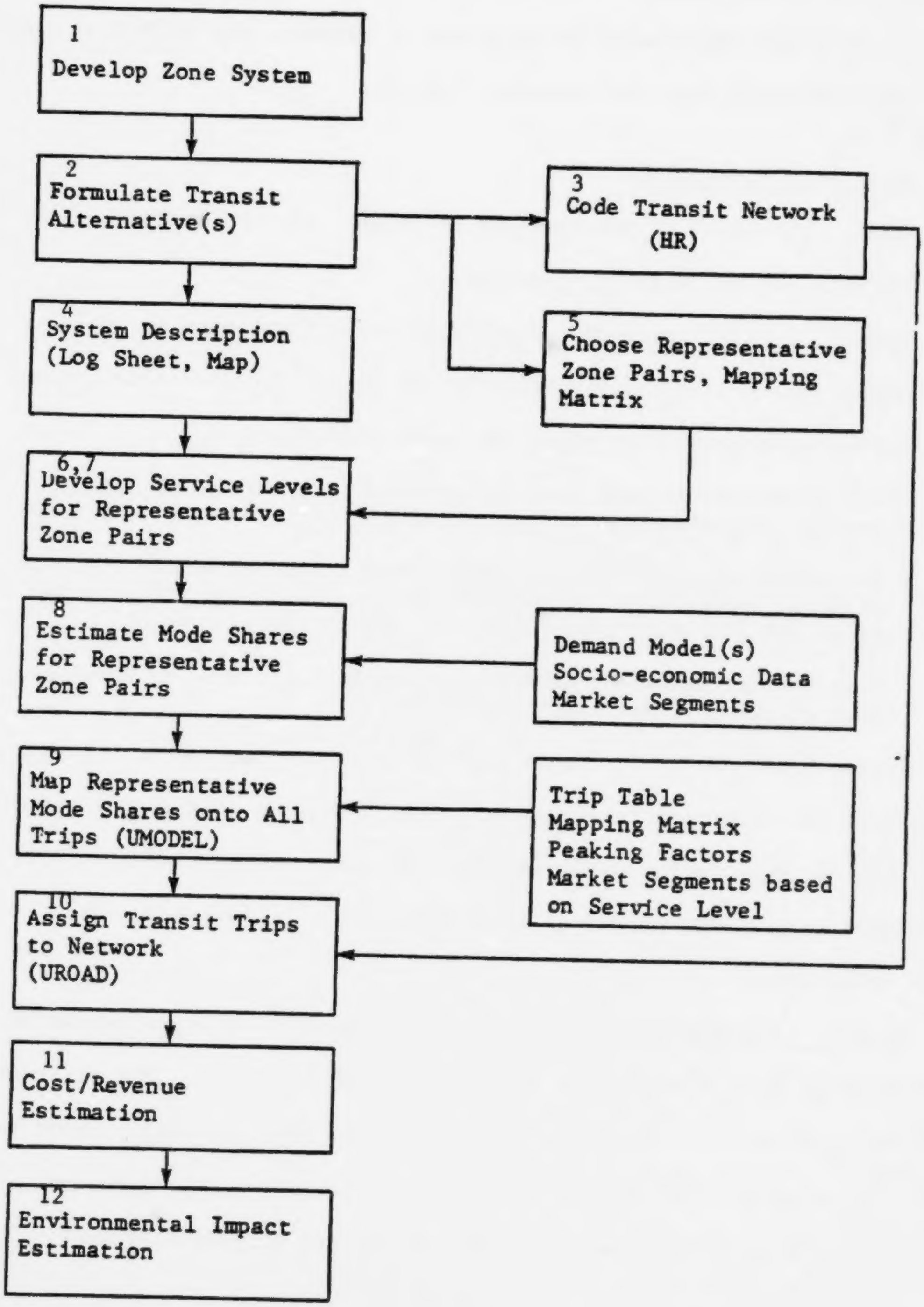
The transit sketch planning procedure (Volume I, Section 2.3.3) selected for the analysis is particularly well-suited to the analysis and initial screening of a large number of transit system development alternatives. Its simplified structure and the incorporation of manual worksheet techniques makes it relatively inexpensive to set up; and the utilization of computer steps using UTPS programs reduces the computational burden associated with analyzing a large number of alternatives.

D. Overview of the Analysis

The sequence of steps followed in applying the transit sketch planning procedure is shown in Figure V-2. First, a zone system is established by aggregating existing traffic zones to form up to 100 analysis zones. Formulation of the transit alternative is accomplished by means of system description log sheets, which summarize specific characteristics of the alternative, and a simplified transit network coded through the use of UTPS program HR. Next, a sample of representative trips are chosen for detailed demand analysis, the results of which will be mapped onto all other origin/destination pairs. Market segments based on transit access mode are defined for these zone pairs, and service levels are developed for each market segment. Then, travel demand models are applied manually to estimate mode shares for representative zone pairs. These representative mode shares are then mapped onto all origin/destination pairs

FIGURE V-2

Major Steps in Sketch Planning Procedure


1
Develop Zone System
2
Formulate Transit Alternative(s)
3
Code Transit Network (HR)
4
System Description (Log Sheet, Map)
5
Choose Representative Zone Pairs, Mapping Matrix
6,7
Develop Service Levels for Representative Zone Pairs
8
Estimate Mode Shares for Representative Zone Pairs
Demand Model(s)
Socio-economic Data
Market Segments
9
Map Representative Mode Shares onto All Trips (UMODEL)
Trip Table
Mapping Matrix
Peaking Factors
Market Segments based on Service Level
10
Assign Transit Trips to Network (UROAD)
11
Cost/Revenue Estimation
12
Environmental Impact Estimation

using a user-coded version of the UTPS program UMODEL. UMODEL produces transit trip tables which are assigned to the transit network using UROAD. A series of manual worksheets is completed to estimate the transit system's cost and performance and environmental impacts.

E. Input Data Development

Steps 1 through 7 of the analysis procedure involve the development of input data and an analysis framework.

Step 1: Establishment of a Zone System--The first step in applying the transit sketch planning procedure is the definition of a zone system. Three criteria were used to define the zonal structure:

- the boundaries of each zone are located to avoid having multiple transit routes with differing levels of service in the same zone;
- the number of intrazonal trips was kept to approximately 5 percent using an approximate relationship between interzonal trip making rates and zone size included in the sketch planning model;
- zone boundaries were constructed to conform, as much as possible with existing census tract boundaries.

The 32-zone system shown in Figure V-3 was developed for use in the analysis of each of the proposed transit alternatives. Between 30 and 40 zones will typically be adequate for use in analyzing a small to medium-sized city. A somewhat larger zone system would be required to analyze an entire large urban area.

Step 2: Formulation of Transit Alternative--The busway alternative considered in this illustration was described in Section B. The alternatives to be analyzed must be developed in at least the level of detail shown in Figure IV-1. Headways, station spacings, service hours, and fares developed for all transit services, and routes are defined at a level

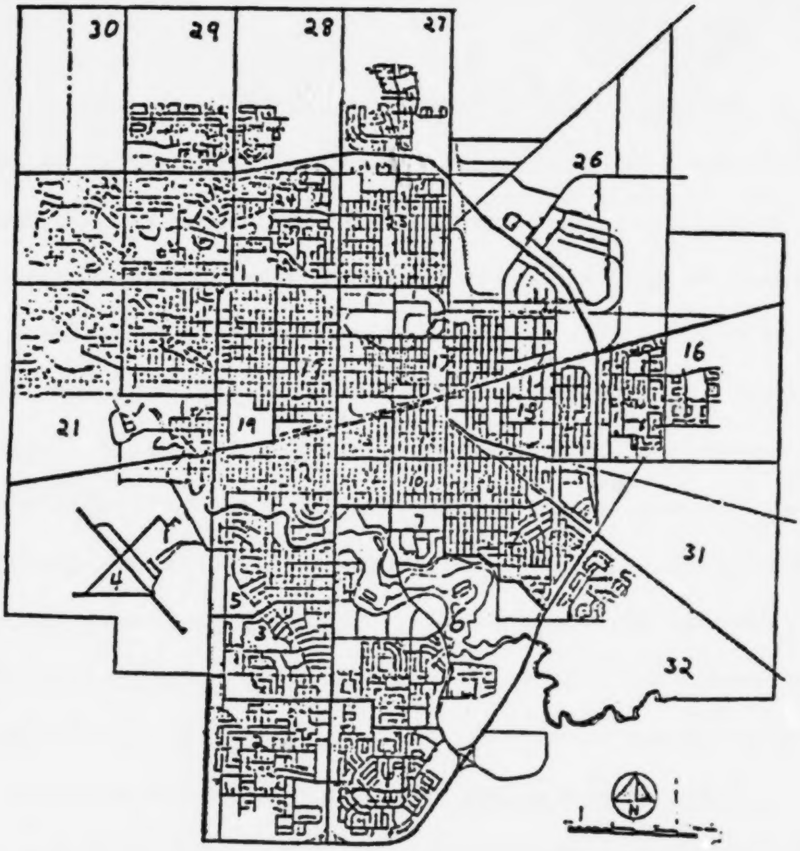


FIGURE V-3

1987 Transit Zones

specific enough to indicate the level of transit service available in each of the analysis zones defined in Step 1. A map such as the one shown in Figure V-1 is adequate for the purpose of defining the proposed transit system.

Step 3: Network Coding--A network was coded to correspond to the busway system shown in Figure V-1. The network consisted of 56 centroid connectors and 75 links representing the transit services. No specific route structure or headways are coded in the network explicitly--only link travel times are used. Also, no feeder system information is coded in the network. Each of these considerations is dealt with manually in defining transit level of service between zones. The coded transit network is used only for assigning transit trips once the transit mode share has been determined using manual or programmable calculator procedures. Finally, no highway network was coded. Highway zone-to-zone travel times used in the demand model were obtained from actual surveys conducted in 1976, and were assumed to increase by 10 percent in the 1987 analysis year.

Step 4: Detailed System Description--The system description log sheet sheet shown in Figure V-4 is used to specify the characteristics of the proposed transit services. All of the variables shown on the system description log sheet must be relatively constant over the system being analyzed.

Step 5: Choice of Representative Trips--Seventeen zone pairs were selected to represent trip making throughout the urban area (up to 18 zone pairs may be used in the sketch planning procedure). The representative zone (O-D) pairs were selected so as to cover the range of trip types in the urban area. Table V-1 shows the O-D pairs selected and the type of

Option: Busway
Time Period: Peak

Technology: Linehaul 1 Bus
Linehaul 2 Bus
Feeder Minibus

Operation: Linehaul 1 Express
Linehaul 2 Local
Feeder Dial-a-ride

Station Spacing: Linehaul 1 0.8 mi.
Linehaul 2 0.1 mi.

Vehicle Size: Linehaul 1 50 seats
Linehaul 2 50 seats
Feeder 24 seats

Feeder Service: Area of Zones 0.8 mi.^{2}
Integrated with linehaul ____ or separate X ?
If separate, headway 12 minutes

Linehaul Service 1: Headway, CBD routes 12 minutes
Headway, non-CBD routes - minutes
Average number of intermediate stops all (CBD routes)

Linehaul Service 2: Headway, CBD routes 12 minutes
Headway, non-CBD routes - minutes
Average number of intermediate stops all (CBD routes)

Fare: Linehaul 1: 45 cents
Linehaul 2: 30 cents
Zone: 0 cents (trips over ____ miles)
Feeder: 45 cents
Transfer: 0

Speed: Linehaul 1: 20 mph (with X or without ____ stops)
Linehaul 2: 12 mph (with X or without ____ stops)
CBD Linehaul: 6 mph (with stops)
Feeder: 10 mph (with stops)

Other: See supplementary sheet describing auto disincentives.

FIGURE V-4

System Description Log Sheet

TABLE V-1

Representative Trips for the Busway Option

INDEX	O-D PAIR	TRIP CHARACTERISTICS
1	23-13	Regular Transit + Telebus; Medium Distance to CBD
2	8-13	Regular Transit + Telebus; Short Distance to CBD
3	15-13	Express Bus to CBD
4	25-13	Regular Transit; Medium Distance to CBD
5	18-13	Regular Transit; Short Distance to CBD
6	6-1	Crosstown Telebus - Telebus Direct
7	3-1	Crosstown Short Distance; Regular Transit - Telebus
8	31-6	Crosstown Medium Distance; Regular Transit - Telebus + Transfer
9	18-3	Crosstown Medium Distance; Regular Transit + Telebus
10	19-9	Crosstown Medium Distance; Regular Transit
11	15-7	Crosstown Short Distance; Regular Transit
12	28-7	Crosstown Long Distance; Regular Transit
13	22-22	Intra-zone Telebus
14	17-17	Intra-zone Regular Transit
15	29-13	Busway to CBD
16	22-8	Crosstown Long Distance Busway
17	25-15	Crosstown Medium Distance Busway

trip represented by each.[1] Note that the characteristics of the transit alternative under study, as well as the location of the zones in the O-D pair define the type of trip a given pair is chosen to represent. The number of representative O-D pairs necessary to reflect the range of trip types is a function of the characteristics of the urban area under study, and the extent and variety of transit services being analyzed.

Once representative zone pairs had been identified, a mapping matrix was developed relating each possible zone-pair to one of the selected representative trips. The classification of zone pairs relies to a great extent on analyst judgment, based on a knowledge of the urban area and the proposed transit system. Travel demand model coefficients aid in the classification process by identifying the most sensitive variables to consider in matching zone pairs and representative trips.

Step 6: Market Segmentation Based on Service Level--Each zone was then broken into market segments defined by the type of access to transit service. Table V-2 shows the way in which the market segmentation is prepared as input for the model. Each of the 32 zones is divided into three "subzones": near, middle, and far. The near subzone is the area of the zone located within 0.25 miles of the linehaul transit route; potential transit users are assumed to walk to the route from this area. The middle subzone is the area beyond 0.25 miles of the linehaul route, but within 0.25 miles of a feeder service; individuals in this subzone are assumed to use the feeder service. The far subzone is the area beyond a 0.25 mile walk to either a linehaul or feeder route; park-ride or kiss-ride are assumed to

---

[1] Trips between zones are assumed to have the same transportation level of service, regardless of direction.

TABLE V-2

Subzone Percentages Busway Network

	Near Sub-Zone	Middle Sub-Zone	Far Sub-Zone	Total
1	20	80	0	100
2	5	95	0	100
3	20	80	0	100
4	10	0	90	100
5	100	0	0	100
6	75	25	0	100
7	100	0	0	100
8	70	30	0	100
9	90	0	10	100
10	100	0	0	100
11	100	0	0	100
12	85	0	15	100
13	100	0	0	100
14	100	0	0	100
15	50	0	50	100
16	10	90	0	100
17	75	0	25	100
18	75	0	25	100
19	75	0	25	100
20	75	25	0	100
21	5	95	0	100
22	0	100	0	100
23	10	90	0	100
24	10	90	0	100
25	100	0	0	100
26	0	100	0	100
27	0	100	0	100
28	0	100	0	100
29	0	100	0	100
30	0	100	0	100
31	0	100	0	100
32	0	100	0	100

be the only transit access options available. (Note that the procedure assumes that if feeder service is available, it will be used; park-ride or kiss-ride are not available options for users in the middle subzone.)

In the transit demand analysis, market segments are defined on an origin/destination basis for each zone pair. Thus a near-subzone to near-subzone trips corresponds to a walk-to-transit/walk-from-transit market segment. Transit trips are presumed not to serve trips to far-subzones in the destination zone, thus six possible market segments exist for each zone pair, with the size being determined by the product of the sub-zone percentages for the origin and destination zone. Thus, using figures from Table V-2, the Walk/Walk market segment from zone 1 to zone 9 is .20 x .90, or 18 percent of the total zone 1 to zone 9 market. The UTPS program UMODEL described later computes the market segment proportions for all O-D pairs in the urban area.

Step 7: Development of Service Levels for Representative Zone Pairs--For each of the 17 representative zone pairs, it is necessary to code the cost (OPTC), in-vehicle travel time (IVTT), and out-of-vehicle time (OVTT) information for the three modal alternatives used in the demand model: auto drive-alone, auto shared-ride, and transit. This information is developed by the analyst using the transit system map or network, the system description log sheet, a general description of the road system, and general assumptions such as those outlined in Table V-3. Figure V-5 shows the first sheet (of two) used to record the service levels for O-D pair 23-13. Note that service levels are found separately for each market segment in the zone pair; the second sheet contains the remaining four market segments not included in the first sheet.

TABLE V-3

Level of Service Assumptions (1987)

Auto Out-of-Pocket Travel Costs (1987)	12¢ per mile.
Auto In-Vehicle Travel Time	Taken from speed and travel time data provided by City Traffic and Engineering Departments
Auto Out-of-Vehicle Travel Time	Two minutes at non-CBD origins or destinations. Three minutes at CBD origins or destinations.
Auto Daily CBD Parking Cost	$1.20
Carpool Auto Occupancy Rate	2.5 persons
Carpool In-Vehicle Travel Time Penalty	Five minutes
Carpool Out-of-Vehicle Travel Time Penalty	One minute
Transit In-Vehicle Travel Time	Taken from Transit System running boards.
Transit Fares	30¢ non-Telebus trips. 45¢ trips with Telebus.
Walk Times to Transit	Three minutes for route. 0.50 minutes for Telebus.
Wait Times at Trip Origin	½ headway for fixed route. Three minutes for Telebus.* Four minutes for transfers which occur in CBD.* ½ headway for non-CBD transfers.
Feeder-Line Haul Transfer	Three minutes.*

Assumptions for Auto Disincentives

Auto Out-of-Vehicle Travel Time	Six minutes for CBD origins or destinations.
Auto Daily CBD Parking Cost	$2.40

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*Coordinated transfers.

System [illegible] Operating Policy *Moderate* Year *1987*
Description
Origin *23* Destination *13* Auto Distance *3.4 miles*
(All Values are One-Way Values)

DRIVE ALONE

OPTC: *12* ¢/mile x *3.4* auto miles + *60* (½ daily parking cost) = *101* cts.
IVTT: [illegible] min/mile (*12* mph) x *3.4* auto miles = *18* min.
OVTT: *2 + 3* = *5* min.

CARPOOL

OPTC: *101* Drive Alone OPTC/ *2.5* auto occupancy rate = *40* cts.
IVTT: *18* Drive Alone IVTT + *5* min. penalty = *23* min.
OVTT: *5* Drive Alone OVTT + *1* min. penalty = *6* min.

TRANSIT LINEHAUL IVTT

Operation	(mph)		min/mile		miles		
Bus on local streets		:		x		=	min.
Bus on freeway		:		x		=	min.
		:		x		=	min.
		:		x		=	min.
		:		x		=	min.

Number of linehaul (station) stops (if applicable) ___ x min/stop ___ = ___ min.
Total Linehaul IVTT *(IVTT was taken from a travel time map in Regina)* = *15* min.

TRANSIT NEAR-NEAR

OPTC = Linehaul one-way fare *45* = *45* cts.
IVTT = Linehaul IVTT *15* = *15* min.
OVTT = Walk at O *3*
+ Linehaul wait at O *6*
+ Linehaul transfers *0*
+ Walk at D *3* = *12* min.

TRANSIT NEAR-MIDDLE

OPTC = Linehaul one-way fare *45*
+ Feeder fare at D *0* = *45* cts.
IVTT = Linehaul IVTT *15*
+ Feeder IVTT at D *12* = *27* min.
(Feeder IVTT at = ___ miles/min. (speed) x ___ miles (feeder distances at D)

OVTT = Walk at O *3*
+ Linehaul wait at O *3*
+ Linehaul transfers *0*
+ Feeder wait at D (zero if integrated) *3*
+ Walk from feeder at D *3* = *12* min.

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FIGURE V-5

Basic Level of Service Coding (Sheet 1)

F. Description of Model Application

Steps 8 through 10 involve the estimation of mode shares for the transit, carpool, and drive-alone modes. First, the representative work and non-work mode shares for each market segment in each O-D pair are calculated using either manual worksheets or a programmable calculator version of the worksheets. The representative zone pair results are then mapped onto total trips in the city using the mapping matrix of Figure V-6 and a user coded version of the UTPS Program UMODEL. The predicted zone-to-zone transit trips are then assigned to the transit network coded in Step 3 using the UTPS program UROAD.

Step 8: Estimate Mode Shares for Representative Zone Pairs--Figures V-7 and V-8 show the worksheets used to calculate the transit mode splits for each of the representative trips for the peak and off-peak period for O-D pair 23-13. Mode splits are calculated for each zone pair and each market segment separately using the information coded in Figure V-4. For this study, the modelling did not consider park-and-ride or kiss-and ride trips because of the city's small size; trips originating in the far subzone of each zone were assumed to not have transit service available. Both of the demand models used in this application of the transit sketch planning procedure were disaggregate travel demand models transferred from Washington, D.C., and updated for application to this urban area.[1]

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[1] For a description of the technique for updating disaggregate travel demand models, see Atherton, Terry J. and Moshe Ben-Akiva, "Transferability and Updating of Disaggregate Travel Demand Models," Transportation Research Record 610, Transportation Research Board, Washington, D.C., 1977.

Map of Representative Trips

From/To Zone	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
1	13																															
2	7	13																														
3	7	6	13																													
4	11	11	16	14																												
5	11	16	16	11	14																											
6	6	7	7	11	11	13																										
7	11	11	11	11	11	11	14																									
8	9	16	16	16	16	8	10	13																								
9	10	17	17	17	17	11	8	10	14																							
10	11	17	17	17	17	11	11	10	11	14																						
11	1	15	15	4	15	1	4	16	15	5	14																					
12	11	16	16	10	16	11	11	11	11	11	10	14																				
13	1	15	15	4	15	1	4	16	4	5	5	10	14																			
14	11	15	15	10	15	10	10	15	10	11	5	10	5	14																		
15	10	17	17	17	11	11	11	17	10	11	3	1	3	10	14																	
16	9	17	17	17	17	10	11	17	10	11	1	11	1	1	10	13																
17	10	17	17	17	17	10	11	17	11	11	3	10	3	11	11	11	14															
18	9	12	12	12	12	10	11	12	11	11	5	11	5	11	11	11	11	14														
19	9	12	12	12	12	9	11	12	10	10	5	11	5	11	10	10	10	10	14													
20	17	17	17	17	17	9	12	17	12	12	17	12	17	17	17	17	12	10	10	13												
21	17	17	17	17	17	9	12	12	17	17	17	12	17	17	17	17	12	10	10	6	13											
22	17	16	16	16	16	17	12	16	16	12	15	12	15	15	15	17	12	10	8	8	6	13										
23	17	16	16	16	16	17	17	17	16	12	15	12	15	15	15	17	17	12	10	8	8	6	13									
24	17	16	16	16	16	17	12	16	16	12	15	12	15	15	15	17	17	12	10	8	8	7	7	13								
25	9	16	16	16	17	9	10	17	9	9	4	10	4	11	10	10	11	9	9	17	17	17	17	11	14							
26	10	10	10	9	10	10	10	12	10	10	4	9	4	11	10	10	10	10	10	12	12	12	12	12	10	13						
27	9	17	17	17	17	17	10	10	10	10	2	10	2	10	10	7	11	9	9	17	17	17	17	17	9	10	13					
28	17	16	16	16	16	17	12	15	12	12	15	12	15	15	17	17	12	12	12	9	9	12	12	17	10	12	8	13				
29	17	16	16	16	16	17	12	15	12	15	15	12	15	15	17	17	12	12	12	9	9	12	12	8	11	12	8	8	13			
30	17	16	16	16	16	17	12	12	12	12	15	12	15	15	17	17	12	12	12	12	12	9	9	8	11	12	17	8	8	13		
31	17	16	16	16	16	17	17	16	16	12	15	12	15	15	17	17	12	12	12	17	17	6	16	16	17	12	17	16	16	16	13	
32	17	16	16	16	16	17	17	16	16	12	15	12	15	15	17	15	12	12	12	17	17	16	16	16	17	12	17	16	16	16	6	13

FIGURE V-6

Mapping Matrix

FIGURE V-7

Work Mode Choice Sheet

System *Busway* Year *1987*

Description

Origin *23* Destination *13* Distance *3.4 miles*

SOCIO-ECONOMIC ATTRIBUTES

U'p = -3.066 + .000044 DINC *14975* = $\boxed{-2.41}$ (U'p)

U'c = -1.777 + 3.35 AALD *.83* + .896 BW *.54*

-.998 DCITY *1* + .000044 DINC *14975* = $\boxed{.46}$ (U'c)

U's = -1.448 + 1.68 AALD *.83* -.514 DCITY *1*

+ .000044 DINC *14975* + .036 NWORK *1.85*

+ .00084 DTECA *0* = $\boxed{-.20}$ (U's)

TOTAL UTILITIES

β_1 = -27/INC 1 = *-.0015* β_2 = *-.0214* β_3 = -.046/DIST = *-.014*

MODE	U'm		(OPTC x β_1	+ IVTT x β_2	+ OVTT X β_3)	= Um	e^{U_m}	Transit Mode Share	
Drive Alone	*.48*	+2	(		)	= *-.39*	*.67*		
Car-Pool	*-.20*	+2	(		)	= *-1.01*	*.36*		
Transit									
NR-NR	0	+2	(		)	= *-.81*	*.44*	*.30*	(NN)
NR-MID	0	+2	(		)	= *-*	*-*	*-*	(NM)
MID-NR	0	+2	(		)	= *-1.03*	*.36*	*.26*	(MN)
MID-MID	0	+2	(		)	= *-*	*-*	*-*	(MM)
FAR-NR U p		+2	(		)	= *-*	*-*	*-*	(FN)
FAR-MID		+2	(		)	= *-*	*-*	*-*	(FM)

FIGURE V-8

Non-Work Mode Choice Sheet

System *Busway* Operating Policy *Moderate* Year *1987*

Description

Origin *29* Destination *13* Distance *4.8 miles*

SOCIO-ECONOMIC ATTRIBUTES

U'c = -.462 + .605 AAC *1.38* = $\boxed{-.365}$ (U'c)

TOTAL UTILITIES

β_1 = -.0203/INC 2 = *-.0025* β_2 = -.0220/DIST = *-.0220* β_3 = *-2.122*

MODE			(OPTC x β_1	+ OVTT x β_2	+ ln(IVTT+OVTT) x β_3)	= Um	e^{U_m}	Transit Share	
Auto	-*.365*	-2(		+	+)	=			
Transit:									
NR-NR	0	-2(		+	+)	=		*.36*	(NN)
NR-MID	0	-2(		+	+)	=		*.16*	(NM)
MID-NR	0	-2(		+	+)	=		*.18*	(MN)
MID-MID	0	-2(		+	+)	=		*.07*	(MM)
FAR-NR	0	-2(		+	+)	=		*--*	(FN)
FAR-MID	0	-2(		+	+)	=		*--*	(FM)

No market segmentation based on socioeconomic characteristics was used in this particular application. This decision was made in part due to resource constraints, and also because of the relative homogeneity of households in many zones in the city. In the most general version of the model, however, Figures V-7 and V-8 would reflect market segmentation by auto ownership level or other socioeconomic characteristics as well as location within the zone. The variables used in these worksheets are defined in Figure V-5.

Step 9: Map Representative Mode Shares Onto All Trips (UMODEL)--A user-coded version of UMODEL is used for this step; the inputs to the program are:

- a set of directional peaking factors, derived from local highway and transit system data if possible; otherwise default values are included in the model;
- proportion of households in each subzone or service level market segment, by zone;
- mapping matrix that translates representative O-D pairs onto all O-D pairs;
- mode shares calculated for each representative trip, by market segment.

Note that UMODEL must be run separately for peak and off-peak analyses since different service levels, service level market segments, mode shares, and peaking factors normally will exist for each of these periods. UMODEL produces four basic outputs:

- a set of zone-to-zone person trip tables by mode
- a trip end summary of person trips by mode
- a trip end summary of transit trips by access mode (subzone)
- a trip end summary of transit revenue by access mode; an additional input--fares by service market segment for each representative zone pair--is required if this output is desired.

Step 10: Network Assignment (UROAD)--The transit trip tables produced by the UMODEL program are assigned to the networks prepared earlier using the UROAD assignment program. All transit trips are assigned on an all-or-nothing basis (UROAD selects the single shortest path for each O-D pair and assigns all trips to that path.) The link loads are plotted on network maps and balanced manually, if required.

G. Impact Assessment

Steps 11 and 12 of the sketch planning procedure involve the use of manual calculation worksheets to estimate the cost and performance characteristics of the proposed busway system, and the change in fuel consumption, emissions, and traffic accidents for both autos and transit.

Step 11: Cost and Performance Estimation--A series of manual worksheets are used in this step to determine the bus system's performance and capital and operating costs. The peak period annual operating costs are calculated using the worksheet shown in Figure V-9. Route mile and headway data are used to calculate the hourly vehicle miles required to cover the system in the peak hour on lines 1 through 3. The annual vehicle mileage-related cost for the fixed route system is calculated in line 4, assuming a 43-cent-per-mile operating cost. Similar calculations are used to determine the annual mileage-related costs for the demand responsive feeder service in Lines 5 and 6. Line 7 is used to determine the number of vehicles required to provide the peak period service, and Line 8 uses this information to calculate the annual vehicle-hour related expenses, based on an hourly cost of $15.63. Finally, other operating expenses are calculated in Line 9, and the total annual operating expense for the proposed

System Busway Operating Policy Moderate Service Level Year 1987

PEAK PERIOD OPERATING COST

1. $VM^{loc}_{1h} = RMI^{loc}_{pk}\ \underline{90} \times 60/H^{pk}_{loc}\ \underline{12} = \boxed{450}\ VM^{1h}_{loc}$

2. $VM^{exp}_{1h} = RMI^{exp}_{pk}\ \underline{17.5} \times 60/H^{pk}_{exp.}\ \underline{30} = \boxed{35}\ VM^{1h}_{exp}$

3. $VM^{bw}_{1h} = RMI^{bw}_{pk}\ \underline{25.6} \times 60/H^{pk}_{bw}\ \underline{12} = \boxed{128}\ VM_{bw}$

4. $CVM_{1m} = (VM^{1h}_{loc}\ \underline{450} + VM^{1h}_{exp}\ \underline{35+128}\,) \times C_{1h}\ \underline{0.43}\ (\underline{1500}\,\text{pk.hr./yr}) = \boxed{.395M}\ CVM_{1h}$

5. $$VM_{c/d} = \left(\frac{Z^{pk}_{fix}\ \underline{-} \times D^{c/d}_{fix}\ \underline{-}}{H^{pk}_{fix}\ \underline{-}} + \frac{Z^{pk}_{dr}\ \underline{29^{*}} \times D^{c/d}_{dr}\ \underline{4.0}}{H^{pk}_{dr}\ \underline{12}} \right) \times 60 = \boxed{580}\ VM_{c/d}$$

6. $CVM_{c/d} = VM_{c/d}\ \underline{580}\ C_{c/d}\ \underline{0.43} \times (\underline{1500}\,\text{pk.hr/yr}) = \boxed{.232M}\ CVM_{c/d}$

7. $$NV^{pk}_{1h} = \frac{60 \times VM^{loc}_{1h}\ \underline{450}}{(50-L)\,\underline{55} \times S_{loc}\ \underline{10}} + \frac{60 \times VM^{exp}_{1h}\ \underline{35}}{(60-L)\,\underline{55} \times S_{exp}\ \underline{15}} + \frac{60 \times VM^{bw}_{1h}\ \underline{128}}{(60-L)\ \underline{55} \times S_{bw}\ \underline{20}} + \text{Extras}\ \underline{20} = \boxed{80}\ NV^{pk}_{1h}$$

$\underline{29}$ Zones* × $\underline{2}$ $= \boxed{58}\ NV^{pk}_{c/d}$

8. $CH = (NV^{pk}_{1h}\ \underline{80} + NV^{pk}_{c/d}\ \underline{58}\,) \times C_h\ \underline{15.63} \times (\underline{1500}\,\text{Pk.hr./yr}) = \boxed{3.235M}\ CH$

9. $COP_{oth} = CFO\ \underline{0} + (C_{go}\ \underline{0} \times G\ \underline{-}\,) + (C_{sd}\ \underline{-} \times NS\ \underline{-}\,) + (C_{bo}\ \underline{6,667} \times NV\ \underline{138}\,/u\ \underline{.8}\,) = \boxed{1.15\ M}\ COP_{oth}$

$COP^{tot}_{pk} = \boxed{5.013M}$

*Number of demand-responsive zones based on peak demand-responsive demand.

FIGURE V-9

Peak Period Operating Cost Sheet

system is determined by adding lines 4, 6, 8 and 9. Similar calculations are carried out on the worksheet in Figure V-10 to determine the total capital cost of the system based on the number of vehicles of each type required, the per vehicle cost, and the cost of the guideway. Both total and equivalent annual capital costs are calculated.

Step 12: Estimate Environmental Impacts--Simple manual worksheets for estimating changes in emissions, fuel consumption and accidents are available within the sketch planning procedure. Changes in annual auto VMT are used as base data in the calculations. The base case VMT for the analysis year must be determined by running the model system with a transit system reflecting existing conditions. The VMT predicted for each transit alternative under study is then compared to the base VMT to determine VMT changes. The worksheet for calculating emissions is shown in Figure V-11. The annual change in total emissions is calculated solely from the predicted change in VMT for autos and buses. Auto emissions rates for CO, HC, and NOx are determined from Table D.7 in Volume I, based on an assumed travel speed, and bus emission rates acquired from EPA Report AP-42.[1] A more sophisticated and accurate appraisal of the air quality impact of the alternative transit systems could be made using the auto emissions worksheets (see Volume I, Section 4.1).

H. Interpretation of Results

The manual sketch planning procedure as applied to the busway alternative provides a comprehensive set of estimates of the impact of transit development alternatives. Data on capital and operating cost, revenue,

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[1] Environmental Protection Agency, "Compilation of Pollutant Emissions Factors," EPA Report AP-42, Second Edition, 1976.

System *Buswan* Operating Policy *Moderate* Technology *Bus* Time Period *1987*

CAPITAL COST (Repeat this block for each technology)

$NV_{lh} = NV_{lh}^{pk} / (u \underline{.8})$ = $\boxed{75}$ NV_{lh}

$CV_{lh} = NV_{lh} \times C_{lh} \underline{96.9K}$ = $\boxed{7.27M}$ CV_{lh}

$CV'_{lh} = NV_{lh} \times crf_{vlh} \underline{.067}$ = CV'_{lh} $\boxed{.487M}$

$NV_{art} = NV_{art}^{pk} / (u \underline{.8})$ = $\boxed{25}$ NV_{art}

$CV_{art} = NV_{art} \times C_{art} \underline{277K}$ = $\boxed{6.93M}$ CV_{art}

$CV'_{art} = CV_{art} \times crf_{art} \underline{.067}$ = CV'_{art} $\boxed{.464M}$

$NV_{c/d} = NV_{c/d}^{pk} / (u \underline{.8})$ = $\boxed{73}$ $NV_{c/d}$

$CV_{c/d} = NV_{c/d} \times C_{c/d} \underline{38.7K}$ = $\boxed{2.83M}$ $CV_{c/d}$

$CV'_{c/d} = CV_{c/d} \times crf_{vcd} \underline{.167}$ = $CV'_{c/d}$ $\boxed{.472M}$

$CS = NS_{cbd} \underline{\quad} \times C_{scbd} \underline{\quad} + (NS - NS_{cbd}) \underline{\quad} \times C_s \underline{\quad}$ = $\boxed{—}$ CS

$CS' = CS \times crf_s \underline{\quad}$ = CS' $\boxed{—}$

$CG = G_e \underline{\quad} \times C_e \underline{\quad} + G_t \underline{\quad} \times C_t \underline{\quad} + G_g \underline{\quad} \times C_g \underline{7.47M}$ = $\boxed{7.47M}$ CG

$CG' = CG \times crf_g \underline{.0783}$ = CG' $\boxed{.585M}$

$CAP'_{tot} = CV'_{lh} + CV'_{art} + CV'_{c/d} + CS' + CG'$ = Total Annual Capital Cost = CAP'_{tot} $\boxed{2.008M}$

$CAP_{tot} = CV_{lh} + CV_{art} + CV_{c/d} + CS + CG$ = $\boxed{24.48M}$ CAP_{tot}

FIGURE V-10

System Capital Costing Sheet

SYSTEM Busway OPERATING POLICY Moderate COMMENTS 1987 analysis year

ENVIRONMENTAL EFFECTS
(All VMT Figures in Annual Miles x 10^3)

UROAD VMT, THIS ALTERNATIVE		143,333		199,827		
UROAD VMT, TARGET YEAR BASE	-	150,500	-	204,000		
CHANGE IN HIGHWAY VMT	=	-7,167	=	-4,173	X1+X2 = -11,340	ΔVMT_A
		(X1)		(X2)		
STANDARD BUS VMT, THIS ALTERNATIVE		1,226		1,194		
STANDARD BUS VMT, TARGET YEAR BASE	-	994	-	958		
CHANGE IN STANDARD BUS VMT	=	232	=	239	X3+X4 = 471	ΔVMT_{SB}
		(X3)		(X4)		
MINI BUS VMT, THIS ALTERNATIVE		870		822		
MINI BUS VMT, TARGET YEAR BASE	-	214	-	929		
CHANGE IN MINI BUS VMT	=	656	=	-107	X5+X6 = 549	ΔVMT_{MB}
		(X5)		(X6)		

AIR POLLUTION

$\Delta CO = \Delta VMT_A \times CO_A \underline{-283,500} + \Delta VMT_{SB} \times CO_{SB} \underline{+5,134} + \Delta VMT_{MB} \times CO_{MB} \underline{+65,880} = -212,486$ $\Delta CO(kg)$

$\Delta HC = \Delta VMT_A \times HC_A \underline{-22,680} + \Delta VMT_{SB} \times HC_{SB} \underline{+6,924} + \Delta VMT_{MB} \times HC_{MB} \underline{+8,113} = -6,643$ $\Delta HC(kg)$

$\Delta NOX = \Delta VMT_A \times NOX_A \underline{-35,154} + \Delta VMT_{SB} \times NOX_{SB} \underline{+6,500} + \Delta VMT_{MB} \times NOX_{SB} \underline{+4,337} = -24,317$ $\Delta NOX(kg)$

FIGURE V-11

Environmental Impacts Sheet

ridership, VMT, fuel consumption and air quality are developed in an integrated procedure. Table V-5 illustrates the type of system impact summary which can be developed for each of a range of alternative transportation systems. The information available from the procedure is sufficient to screen out a small subset of attractive options for further development and detailed analysis.

OPERATING CHARACTERISTICS

	Peak Hours	Off Peak	Totals
ANNUAL SERVICE HOURS	207,000	182,600	389,600
ANNUAL VEHICLE MILES			
Large Bus Miles	1,226,000 (1,962,000)	1,194,000 (1,910,000)	2,421,000 (3,874,000)
Mini Bus Miles	870,000 (1,392,000)	822,000 (1,315,000)	1,692,000 (2,707,000)
Total Bus Miles	2,096,000 (3,354,000)	2,016,000 (3,225,000)	4,113,000 (6,581,000)
Auto Miles (000's)	143,333 (229,333)	199,827 (319,722)	343,159 (549,056)
ANNUAL RIDERSHIP	7,051,000	6,318,000	13,369,000
ANNUAL COSTS (1976 $)			
Operating Costs	5,013,000 *5,833,000*	3,665,000 *4,073,000*	8,679,000 *9,906,000*
Capital Costs	2,007,000	-	2,007,000
Total Costs	-	-	10,686,000 *11,913,000*
ANNUAL REVENUES (1976 $)	2,343,000	1,650,000	3,993,000
ANNUAL DEFICIT	-	-	8,693,000 *7,920,000*

Note: *Figures in Italics show "high" trend in driver wages.*
Figures in Parenthesis show metric equivalents in km.

TABLE V-4

Impact Summary for Busway Transit Option

SERVICE CHARACTERISTICS

	Peak Hours	Off-Peak
ONE-WAY ROUTE MILES		
Conven. Fixed Route	90(144)	79(126)
Fixed Route Feeder	-	-
Telebus Feeder(approx.)	116(186)	71(114)
Express Bus	17.5(28)	-
Express Bus (Busway)	25.6(50)	25.6(50)
Total Route Miles	249(399)	175.6(281)
FEEDER ZONES		
Fixed Route Lines	-	-
Buses/Line	-	-
Telebus Zones	29	15
Buses/Zone	2	1
VEHICLES REQUIREMENTS		
Articulated Buses	25	
Standard Buses	75	
Mini Buses	73	

UNIT CHARACTERISTICS

PER CAPITA		
Annual Bus-Miles	21.7	(34.7)
Annual Ridership	70.5	*70.5*
Annual Cost	$ 56.4	*$ 62.8*
Annual Deficit	$ 35.3	*$ 41.8*
Annual Auto-Miles	1810	(2896)
PER PASSENGER		
Cost	$ .799	*$.891*
Deficit	.501	*$.592*

CASE STUDY VI

FREEWAY RAMP METERING IN A HEAVILY CONGESTED CORRIDOR

CASE STUDY VI: FREEWAY RAMP METERING IN A HEAVILY CONGESTED CORRIDOR[1]

A. Problem Presentation

The Eastshore Freeway, a major urban highway on the eastern side of San Francisco Bay, serves commuter traffic destined for San Francisco, Oakland, and Berkeley from the Northeast quadrant of the Bay Area (see Figure VI-1). Rapid suburban development oriented around the corridor has lead to increasing peak hour congestion in recent years, with a spillover effect on parallel arterial routes.

The Eastshore Freeway Corridor begins at the junction of three major freeways: I-80 from San Francisco via the Bay Bridge, State Route (SR) 17 from Oakland and the South Bay Area, and I-580 from Oakland and the eastern suburbs. The corridor is approximately 10 miles long.

The freeway is heavily travelled throughout the study section but congestion is particularly bad at the ends. In general, demand diminishes along the study section but at a slower rate than capacity, resulting in bottlenecks and congestion under the present situation. On San Pablo Avenue, a parallel arterial street, traffic is moderate except for several critical intersections with heavy cross-flow, such as University Avenue, Cutting Boulevard and Barrett Avenue (see Figure VI-2).

San Pablo Avenue is a four-lane (occasionally six-lane) signalized major arterial located parallel to the freeway and extending for the entire length of the study section. Figure IV-2 shows its location in relation to the freeway and the placement of signalized intersections.

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[1] This case study was originally developed by the Institute of Transportation Studies, University of California, Berkeley. It has been adapted from material in: Jovanis, Paul P., Wai Ki Yip, and Adolf D. May, FREQ6PE - A Freeway Priority Entry Control Simulation Model, Institute of Transportation Studies, University of California, Berkeley, November 1978.

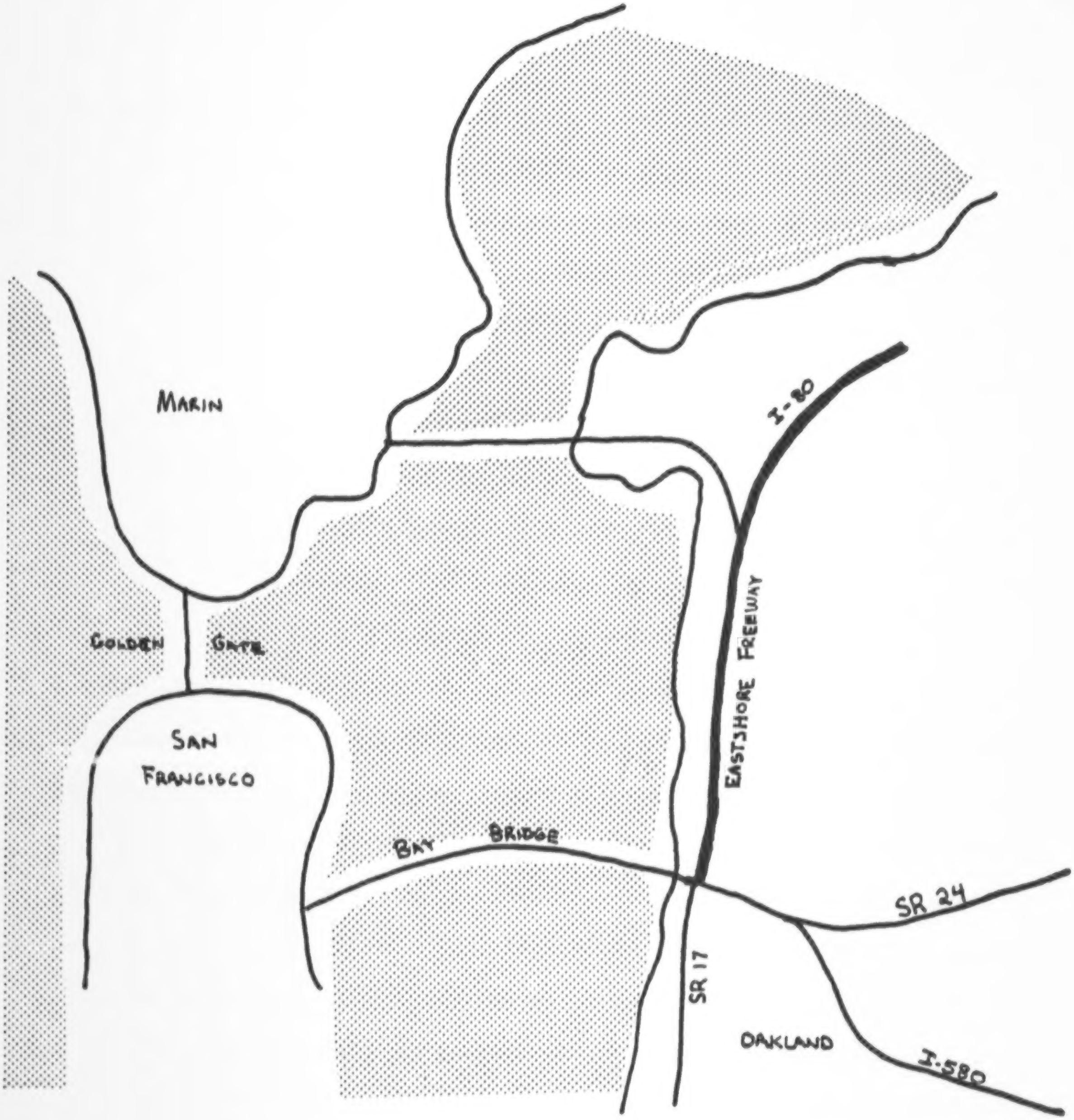

FIGURE IV-1

Location of Eastshore Freeway Corridor

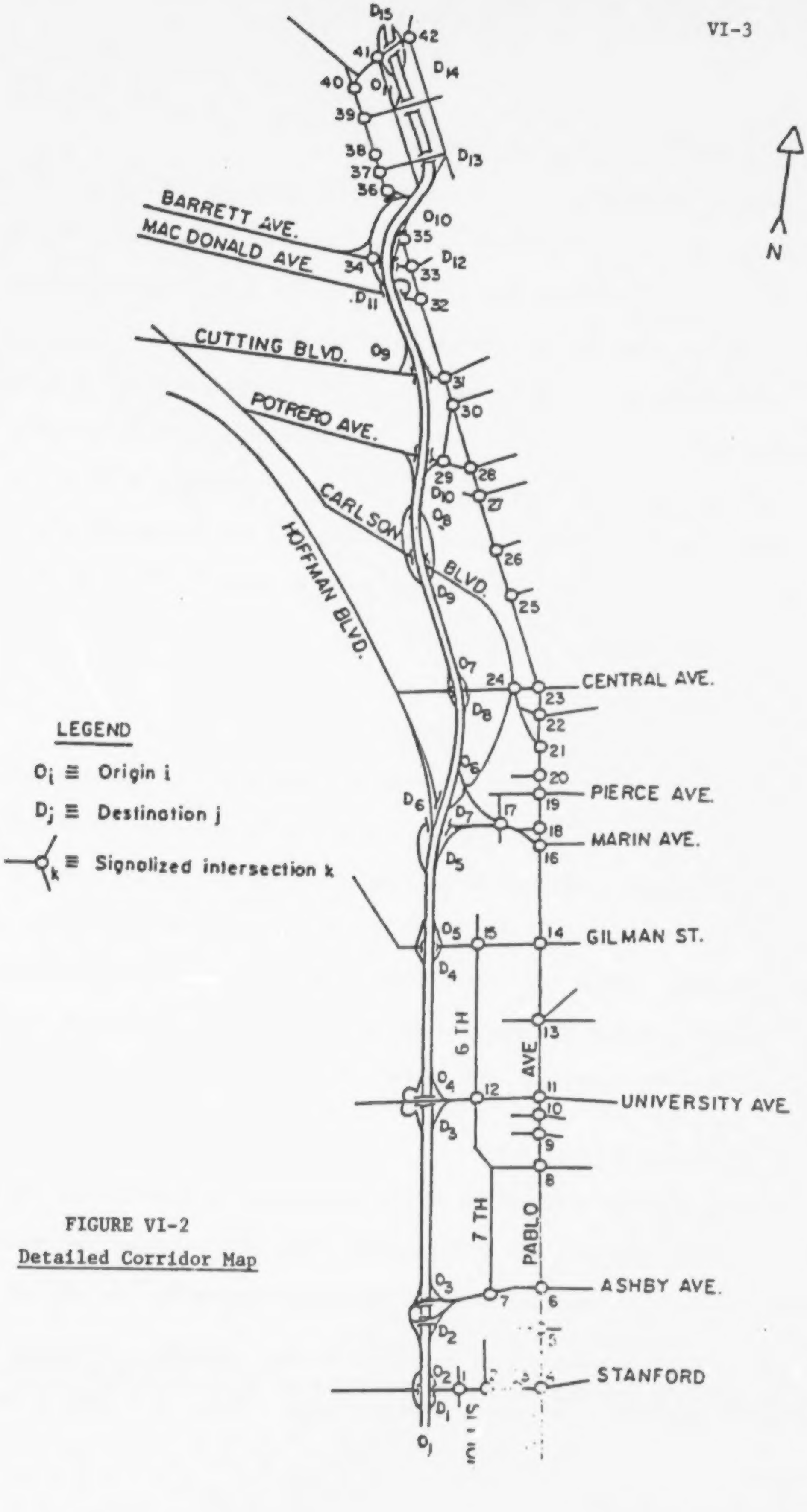

FIGURE VI-2

Detailed Corridor Map

B. Proposed Transportation Measures

Funding limitations and the substantial capacity constraint of the Bay Bridge (five lanes fed by three major freeways) have prompted the consideration of non-construction alternatives for mitigating congestion in the corridor. Ramp metering has been prominent among these proposals.

Two approaches to ramp metering are under consideration; one in which vehicles entering the freeway are controlled without regard to type, and one affording priority ramp entry for multiple occupant vehicles. These strategies are studied for the PM peak only, in the northbound direction, although, in principal, southbound AM congestion could have been evaluated in a similar analysis.

C. Selection of Analysis Technique

Because of the complexity involved in the detailed planning and evaluation of freeway ramp metering on a specific highway, manual sketch planning techniques are not appropriate for this analysis. The computer model FREQ6PE[1] was specifically developed for analyzing freeway measures such as ramp metering. Given its computational power, the data requirements and run expenses for the program are modest. FREQ6PE is, therefore, chosen to analyze the ramp metering options for the Eastshore Freeway.

D. Overview of the Analysis

The major effort involved in the ramp metering analysis is the preparation of input data for the FREQ program. The program itself produces vehicle emissions and fuel consumption impact estimates, as well as a description of traffic flow on the Eastshore Freeway and San Pablo Avenue. FREQ requires a detailed description of freeway and entrance ramp geometry, origin-destination flows, and freeway operating policies, including:

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[1] Jovanis, Paul P., Wai Ki Yip, and Adolf D. May, FREQ6PE - A Freeway Priority Entry Control Simulation Model, Institute of Transportation Studies, University of California, Berkeley, November 1978. Also see Volume I, Section 3.3.2

- "time slices" defined to capture the distinct phases of freeway flow
- no more than 40 subsections of the freeway and their capacity, length, and other characteristics
- similar subsections of the parallel arterial
- ramp capacities
- origin-destination volumes for autos and buses
- base flows on arterial subsections.

The following section describes the development of input data for the analysis.

E. Input Data Development

The input data required for the FREQ6PE model are of three major types: freeway facility data, freeway demand data, and parallel arterial route data. Each of these three data types is described below.

The ten-mile study section was divided into twenty-seven subsections with boundaries signifying changes in traffic demands and/or capacities. The applicable data for each subsection are shown in Figure VI-3. For example, subsection 20 is three-lanes wide, has a capacity of 5880 vehicles per hour, and a length of 1100 feet. It has an origin (on-ramp) at the beginning of the subsection, designated as a special ramp because of the extended length of the merge area. The

SUB SEC	NO. LNS	SSEC CAP	SSEC LENGTH	DESIGN SPEED	ORG DES	TRK FAC	SSEC GRAD	SUR-FACE	SSEC CURV	PCT TRK	PCT DES TRUCKS	SPECIAL RAMP	SUBSECTION LOCATION
1	5	9434.	1630.	55	OD	.94	-0.	1.0	-0.	6	30	NO	MAINLINE ON TO POWELL OFF
2	5	9453.	1960.	55		.96	-0.	1.0	-0.	4	30	NO	POWELL OFF TO POWELL ON
3	5	9615.	1550.	55	OD	.96	-0.	1.0	-0.	4	30	NO	POWELL ON TO ASHBY OFF
4	4	7619.	1960.	55		.95	-0.	1.0	-0.	5	30	NO	ASHBY OFF TO ASHBY ON
5	4	7000.	500.	1*	O	.95	-0.	1.0	-0.	4	30	NO	ASHBY ON TO 500 FT POINT
6	4	7000.	4790.	65	D	.95	-0.	1.0	-0.	4	30	NO	500 FT PT TO UNIVERSITY
7	4	7692.	3030.	65		.96	-0.	1.0	-0.	4	30	NO	UNIVERSITY OFF TO UNIV
8	4	7692.	2160.	65	OD	.96	-0.	1.0	-0.	4	30	NO	UNIVERSITY ON TO GILMAN
9	4	7563.	2030.	65		.96	-0.	1.0	-0.	4	30	NO	GILMAN OFF TO GILMAN ON
10	5	9305.	1250.	65	OD	.97	-0.	1.0	-0.	3	30	NO	GILMAN ON TO BUCHANAN OFF
11	4	7619.	900.	65	D	.95	-0.	1.0	-0.	5	30	YES	BUCHANAN OFF TO HOFFMAN
12	3	5671.	1320.	65	D	.96	-0.	1.0	-0.	4	30	NO	HOFFMAN OFF TO PIERCE OFF
13	3	5750.	720.	65		.96	-0.	1.0	-0.	4	30	NO	PIERCE OFF TO PIERCE ON
14	3	5806.	2610.	65	OD	.97	-0.	1.0	-0.	4	30	NO	PIERCE ON TO CENTRAL OFF
15	3	5728.	1660.	65		.97	-0.	1.0	-0.	3	30	NO	CENTRAL OFF TO CENTRAL ON
16	3	5806.	1890.	65	OD	.97	-0.	1.0	-0.	3	30	NO	CENTRAL ON TO CARLSON ON
17	3	5520.	2310.	65		.94	2.0	1.0	-0.	3	30	NO	CARLSON OFF TO CARLSON ON
18	3	5950.	1460.	65	OD	.98	-0.	1.0	-0.	2	30	NO	CARLSON ON TO POTRERO OFF
19	3	5806.	3800.	65		.97	-0.	1.0	-0.	3	30	NO	POTRERO OFF TO CUTTING ON
20	3	5880.	1100.	65	O	.98	2.0	1.0	-0.	3	30	YES	CUTTING ON TO GRADE CHGE
21	3	5950.	660.	65	D	.98	-0.	1.0	-0.	3	30	NO	GRADE CHGE PT TO MACDONALD
22	3	5950.	1480.	65	D	.98	-0.	1.0	-0.	3	30	NO	MACDONALD OFF TO SAN PABLO
23	3	5728.	1480.	65		.97	-0.	1.0	-0.	2	30	NO	SAN PABLO OFF TO SAN PABLO
24	4	6850.	800.	65	OD	.98	-0.	1.0	-0.	2	30	NO	SAN PABLO ON TO SOLANO ON
25	3	5800.	4690.	65	D	.97	-0.	1.0	-0.	4	30	NO	SOLANO OFF TO S. PABLO ON
26	3	5806.	2190.	65		.97	-0.	1.0	-0.	3	30	NO	DAM ROAD OFF TO DAM RD ON
27	3	5800.	2320.	65	OD	.97	-0.	1.0	-0.	4	30	NO	DAM RD ON TO RD 20 OFF

* INDICATES USER-SUPPLIED SPEED-FLOW CURVE NUMBER

RAMP LIMITS = 1500.
OFF-RAMP 6 LIMIT = 2200.

FIGURE VI-3

Eastshore Freeway Facility Data

subsection has a 2 percent up-grade and a smooth surface, and is on a tangent. Three percent of the vehicles are buses and trucks, and 30 percent of these are diesel powered.

The freeway design speed is used to indicate the appropriate speed-volume/capacity relationship for each subsection. These V/C curves are internal to the program. A sixty-five mph curve was used for subsections 6 through 27 whereas a fifty-five mph curve was used for subsections 1 through 4 because of heavy merging traffic due to the three upstream freeways. An intermediate user supplied curve was used for subsection 5. A capacity value of 1500 vehicles per hour was selected for all ramps except for off-ramp 6, which was assigned a value of 2200 vehicles per hour. Because of the heavy weaving in many areas of the study section, an internal model option was used to decrease the capacity of certain sections.

The afternoon peak in this corridor extends roughly from 3:30 PM to 6:00 PM. Fifteen minute time "slices" were selected for analysis, yielding a total of 10 separate time periods for the peak. Two sets of origin and destination tables were prepared for each time slice: one for passenger vehicles and the other for buses. An example O-D table, for passenger vehicles during the first time slice, is shown in Figure VI-4.[1] All buses enter the freeway at the mainline origin and leave

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[1] These O-D tables were developed from observed flows at each of the on- and off-ramps and at the mainline start and end points. A computer program was used to synthesize O-D voluems consistent with these marginal totals. For some FREQ applications, policy conclusions could be affected by the accuracy of this O-D approximation, in which case it may be desirable to measure the actual flows more directly.

DESTINATION NUMBER

ORIGIN NUMBER	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	228	253	270	67	87	268	19	86	36	57	31	50	28	88	284
2	0	14	15	4	5	15	1	5	2	3	2	3	2	5	17
3	0	0	35	9	11	35	2	11	5	7	4	7	4	12	37
4	0	0	0	13	17	51	4	16	7	11	6	9	5	17	55
5	0	0	0	0	15	46	3	15	6	10	5	8	5	15	49
6	0	0	0	0	0	0	0	5	2	3	2	3	2	5	17
7	0	0	0	0	0	0	0	0	7	10	6	9	5	16	52
8	0	0	0	0	0	0	0	0	0	9	5	8	4	13	43
9	0	0	0	0	0	0	0	0	0	0	14	23	13	40	130
10	0	0	0	0	0	0	0	0	0	0	0	0	10	32	104
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	64

FIGURE VI-4

Sample Origin-Destination Data for Eastshore Freeway - Time Slice One the freeway at one of five off-ramps: Ashby, University, Central, Carlson and the mainline destination. During the period 3:30 to 6:00 PM, a total of 103 buses use the freeway, with an average occupancy of thirty-three persons.

The model also requires an occupancy distribution for passenger vehicles at each ramp, as shown in Figure VI-5. The proportions of single occupant autos and two-, and three-person carpools, as well as the proportion of buses, are specified for each ramp. In addition, the average occupancies for passenger vehicles carrying three or more persons and for buses are specified for each on-ramp.

The arterial, like the freeway, is divided into twenty-seven subsections. Each subsection corresponds to a freeway subsection and requires three types of descriptive information:

- capacity in vehicles per hour;
- free-flow speed in miles per hour; and,
- a variable indicating whether or not there are signals on the subsection, and if there are signals, whether the progression is poor or good.

Figure VI-6 provides these data for San Pablo Avenue. For example, subsection 1 has a capacity of 3630 vehicles per hour, no signals, and a free-flow speed of 30 miles per hour. Subsection 2 has a capacity of 1971 vehicles per hour, contains signals with good progression and has a free-flow speed of twenty-five miles per hour.[1]

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[1] Arterial data for this case were derived from previous TRANSYT modelling work. Typically, one would develop more approximate speed and capacity data for such an arterial based on number of lanes, lane widths, turning movements, and, if possible, more detailed field measurements. The accuracy requirements for these data are less stringent than for the freeway itself.

ON-RAMP	OCCUPANCY				CARPOOL (3+) OCCUPANCY	BUS OCCUPANCY
	1	2	3 OR MORE	BUSES		
1	0.744	0.168	0.078	0.010	3.2	33
2	0.751	0.170	0.079	0.	3.2	0
3	0.751	0.170	0.079	0.	3.2	0
4	0.751	0.170	0.079	0.	3.2	0
5	0.751	0.170	0.079	0.	3.2	0
6	0.751	0.170	0.079	0.	3.2	0
7	0.751	0.170	0.079	0.	3.2	0
8	0.751	0.170	0.079	0.	3.2	0
9	0.751	0.170	0.079	0.	3.2	0
10	0.751	0.170	0.079	0.	3.2	0
11	0.751	0.170	0.079	0.	3.2	0

FIGURE VI-5

Distribution of Passenger Occupancies on the Eastshore Freeway

Subsection	Free-Flow Speed	Capacity	Arterial Type
1	30	3630	NS
2	25	1971	G
3	25	1971	G
4	25	1686	G
5	25	4918	NS
6	27	2224	G
7	20	2681	G
8	28	2529	G
9	23	2155	G
10	26	2515	G
11	26	4300	NS
12	26	2211	G
13	20	2325	G
14	20	2475	G
15	26	3331	G
16	23	2023	G
17	29	2000	G
18	30	1954	G
19	30	2722	G
20	24	5938	NS
21	24	2524	G
22	27	1358	G
23	25	3055	G
24	27	2322	G
25	30	3367	G
26	30	2014	G
27	30	4400	NS

NOTE 1: NS = No Signals; G = Signalization with Good Progression; and P = Signalization with Poor Progression.

FIGURE VI-6

San Pablo Avenue Facility Data

The flow data for the arterial consist of estimates for each subsection for each time slice. The flows are entered on a separate set of cards. In this application, there are ten such sets of cards. Field observations indicated an average occupancy of 1.2 persons per vehicle for San Pablo Avenue, which was used in this model.

F. Description of Model Application and Impact Assessment

Detailed program documentation[1] describes the input format required by FREQ6PE, which will not be described here. The model produces extensive, detailed output for each time slice and subsection, including: flows, volume-capacity ratios, speeds, queue lengths, fuel consumption, and emissions. Attention should be directed to the congestion queue diagram and to the freeway and arterial summary tables.

Base Conditions

The queueing diagram of freeway congestion for the pre-control situation is shown in Figure VI-7. The vertical scale is time and the horizontal scale is distance along the freeway. Time moves up the diagram and traffic moves from left to right. The diagram identifies three separate bottlenecks in subsections 5, 20 and 25, and their accompanying upstream congestion. Congestion first begins at the start of time slice 3 (4:00 PM) and all congestion is over at the end of time slice 9 (5:45 PM). The bottlenecks and accompanying queues are separate from one another and there is a slight offset in the time periods of congestion.

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[1] Jovanis, Yip, and May, op.cit.

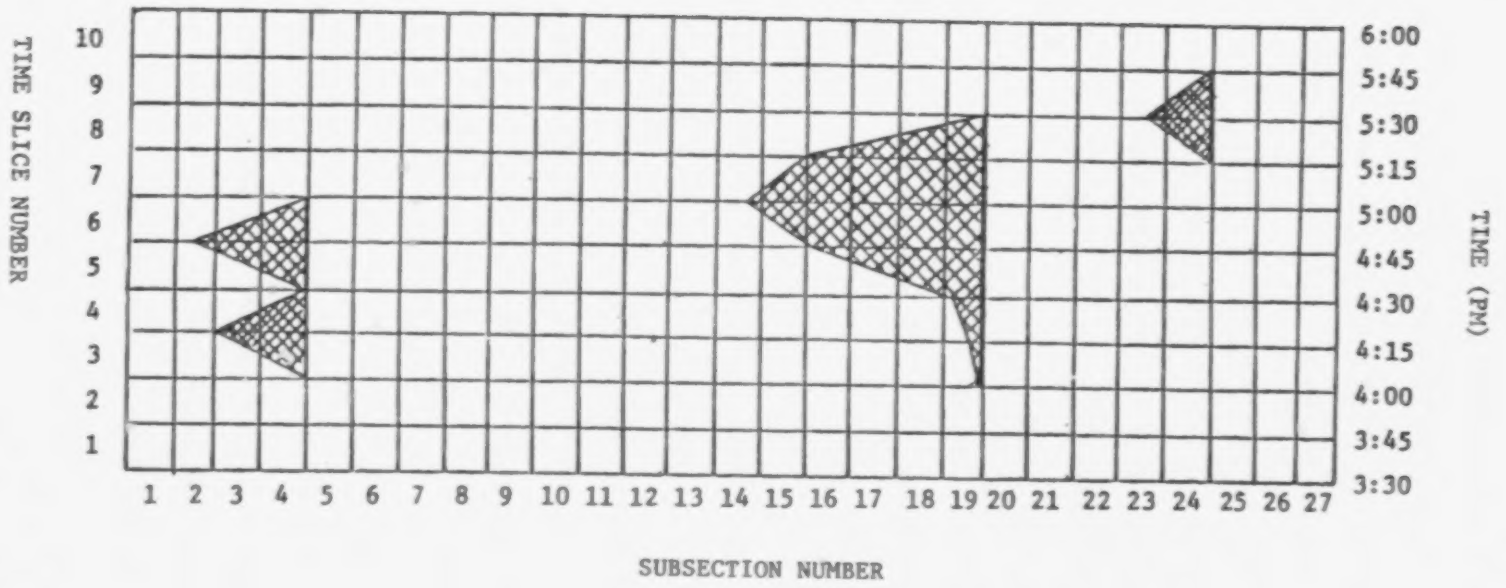

FIGURE VI-7

Queueing Diagram of Freeway Congestion before Entry Control

The bottleneck at subsection 25 is a minor one, resulting in small congestion delays. The congestion due to bottlenecks at subsections 5 and 20 are much more severe. The queueing diagram illustrates a rather complex congestion pattern on the freeway. Just as congestion ends at the upstream end, the queue due to the bottleneck at subsection 20 is at its peak. Again, as congestion ends upstream of subsection 20, the queue in subsections 23 and 24 is at its peak. We may expect this congestion pattern to be reflected in the ramp metering plan and associated traveller responses.

The freeway and arterial summary tables are shown in Figures VI-8 and VI-9. Summary data are presented for each time slice and for the entire analysis period. This information serves as the base condition, and all entry control results are compared with it. For example, in Figure VI-8, the total freeway travel time is 3981 passenger hours, while the arterial time is 1251 passenger hours. The total travel distance is 184,297 passenger miles for the freeway and 28,323 passenger miles for the arterial. The arterial thus carries 15 percent of the corridor passenger miles, yet because of a lower level of service accounts for 30 percent of corridor passenger hours.

Entry Control Analysis

The two entry control situations analyzed included ramp metering without priority ramp lanes and ramp metering with priority ramp lanes. Three analysis phases were undertaken for entry control without bypass priority ramp lanes: analysis with no diversion, analysis with

T.S.	FRWY T. T. VH	FRWY T. T. PH	RAMP DEL. VH	RAMP DEL. PH	TOT. FRWY T.T. VH	TOT. FRWY T.T. PH	FRWY T.D. VM	FRWY T.D. PM	SPD MPH	FUEL Gal.	HC Kg	CO Kg	NO_x Kg	Begin Time
1	221	297	0	0	221	297	12122	16284	54.8	742	33	317	60	3:30
2	240	328	0	0	240	328	13075	17830	54.4	797	35	343	64	3:45
3	303	412	0	0	303	412	14282	19441	47.2	849	40	390	62	4:00
4	305	416	0	0	305	416	14314	19507	46.9	852	40	392	61	4:15
5	350	482	0	0	350	482	14265	19631	40.7	867	43	425	55	4:30
6	375	524	0	0	375	524	14151	19790	37.8	868	44	435	52	4:45
7	333	493	0	0	333	493	13437	19891	40.3	842	41	405	54	5:00
8	280	428	0	0	280	428	12426	18993	44.4	749	36	348	52	5:15
9	200	311	0	0	200	311	10815	16799	54.0	670	29	286	54	5:30
10	189	289	0	0	189	289	10566	16130	55.8	653	28	275	53	5:45
Total	2798	3981	0	0	2798	3981	129454	184297	47.6	7890	370	3617	566	

Where:
T.S. = Time Slice Number.
FRWY T.T. = Freeway Travel Time, excluding any ramp delay.
RAMP DEL. = Ramp Delay
TOT. FRWY T.T. = Total Freeway Travel Time, including ramp delay.
VH = Vehicle Hours
PH = passenger hours
SPD = Speed in miles per hour
FUEL = Fuel consumption in gallons
H.C. = Hydrocarbon emissions in kilograms
CO = Carbon Monoxide emissions in kilograms

NO_x = Nitrous Oxide emissions in kilograms.
Begin Time = The time at the beginning of the slice.

FIGURE VI-8

Eastshore Freeway - Freeway Summary before Entry Control

T.S.	ART. T.T.		ART. T.D.		SPD MPH	FUEL GAL.	HC Kg	CO Kg	NO_x Kg	Begin Time
	VH	PH	VM	PM						
1	86	103	2017	2420	24	188	8	71	2	3:30
2	88	105	2077	2493	24	193	8	73	3	3:45
3	95	114	2200	2639	23	204	9	79	3	4:00
4	100	120	2312	2775	23	215	9	84	3	4:15
5	117	141	2618	3142	22	243	11	100	3	4:30
6	119	143	2652	3183	22	246	11	102	3	4:45
7	121	146	2651	3181	22	246	11	106	3	5:00
8	122	147	2674	3208	22	248	11	106	3	5:15
9	107	128	2351	2821	22	218	10	93	3	5:30
10	88	105	2051	2462	23	191	8	74	2	5:45
Totals	1043	1251	23602	28323	23	2192	94	889	27	

Where:

T.S. = Time Slice Number.
ART. T.T.= Arterial Travel Time; VH = Vehicle Hours, PH = Passenger Hours.
ART. T.D.= Arterial Travel Distance; VM = Vehicle Miles, PM = Passenger Miles.
SPD = Speed in miles per hour.
FUEL = Fuel Consumption in gallons.
H.C. = Hydrocarbon emissions in kilograms.
CO = Carbon Monoxide emissions in kilograms
NO_x = Nitrous Oxide emissions in kilograms
Begin Time = The time at the beginning of the time slice.

FIGURE VI-9

Eastshore Freeway - Arterial Summary Before Entry Control short-term diversion, and analysis with short- and longer-term diversion. The "No Diversion" impacts are those that can be expected to occur on the first day of the operation with a particular entry control plan. The "Short-Term Analysis" takes place from two to four weeks after the start of entry control. The "Longer-Term Analysis" takes place approximately two to four months after the start of entry control.

For the no-diversion case, the ramp metering plan and the resulting ramp queue model, are shown in Figure VI-10. The metering plan calls for seven ramps to be controlled for varying periods of time between 4:00 PM and 5:15 PM. It clearly reflects the congestion pattern illustrated by Figure VI-7. The bottleneck in subsection 5 is relieved by metering on-ramps 2 and 3 during time slices 3, 4 and 5. Equity[1] is reflected in this portion of the metering plan through control of on-ramp 2 despite the location of the bottleneck just downstream of on-ramp 3. Tighter control at ramp 3 alone would have relieved the congestion with lower total delay but at the cost of very high delays for travellers entering the freeway at on-ramp 3.

The congestion caused by the bottlenecks at subsections 20 and 25 is relieved by metering ramps 4, 6, 7, 8 and 9 for varying times between

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[1] The equity considerations of freeway entry control have been a source of much discussion in recent years. Equity here refers to the more equal sharing of ramp metering delays. Through this more equal sharing, more people will pay a small amount in time penalty rather than have a small number of users pay a very large amount (in increased ramp delays). The benefits of entry control still accrue to those who get on the freeway and are now able to travel congestion-free. The costs are merely distributed to more freeway users.

TIME SLICE		ON-RAMP NUMBERS						
		2	3	4	6	7	8	9
3 4:00 - 4:15 PM	Metering Rate (vph) Queued Vehicles (veh) Diverted Vehicles (veh)	180 26 0	269 107 0				218 15 0	
4 4:15 - 4:30 PM	Metering Rate (vph) Queued Vehicles (veh) Diverted Vehicles (veh)	295 30 0				367 21 0	290 21 0	
5 4:30 - 4:45 PM	Metering Rate (vph) Queued Vehicles (veh) Diverted Vehicles (veh)	180 47 0	504 137 0	784 29 0	180 38 0	464 35 0	208 79 0	900 65 0
6 4:45 - 5:00 PM	Metering Rate (vph) Queued Vehicles (veh) Diverted Vehicles (veh)			900 17 0		248 68 0	500 55 0	900 156 0
7 5:00 - 5:15 PM	Metering Rate (vph) Queued Vehicles (veh) Diverted Vehicles (veh)							900 24 0

Legend: On Ramp 2 is Powell Street
3 is Ashby Avenue
4 is University Avenue
On-Ramp 6 is Pierce Street
7 is Central Avenue
8 is Carlson Avenue
On-Ramp 9 is Cutting Boulevard

FIGURE VI-10

Eastshore Freeway Ramp Control Summary: No Bypass Priority Ramp Lanes, No Diversion

4:00 PM and 5:15 PM. Once again, control at on-ramp 9 would have been sufficient to relieve congestion, but massive queues would have accumulated. To avoid these queues, on-ramp 9 is only controlled during time slices 5, 6 and 7, and ramps 4, 6, 7 and 8 are controlled during other time periods. The control at on-ramp 4 during time slices 5 and 6 is an attempt to spread the queues resulting from control to many on-ramps. On-ramp 5 is not metered at all because of heavy input demand (approximately 1200 vphs). Any control at on-ramp 5 would have resulted in very large queues and possible under-utilization of the freeway. In order to prevent on-ramp 5 from being under control, a "No Control" program option was exercised for this ramp from time slice 3 through time slice 8.

A comparison of corridor impacts for the no-diversion and base cases is shown in Figure VI-11. There are varying effects depending on the impacts under consideration. Small travel time savings (2%) are counterbalanced by increases in fuel consumption and vehicle emissions. Similar results for the short and longer term are shown in Figure VI-12. These indicate that even after a longer-term shift in corridor travel patterns, the net effect of undifferentiated ramp metering is to reduce the average delay experienced by travellers, while increasing fuel consumption and pollutant emissions. This is because moderate average speeds under the congested base conditions are not necessarily worse for auto efficiency than the higher speeds made possible by ramp metering. Also, ramp queues with idling vehicles would exacerbate the negative emissions and fuel consumption effects.

		Differences			
		Freeway	Alt. Rte.	Total	% Change
Travel Time	yeh-hr pass-hr	-84 -123	0 0	-84 -123	-2 -2
Fuel Consumption	gal	71	0	71	1
Hydro-Carbons	kg	5	0	5	1
Carbon-Monoxide	kg	83	0	83	2
Nitrous Oxide	kg	50	0	50	8

Note: Differences are values after control minus values before control.

FIGURE VI-11

Eastshore Freeway Differential Effects: Entry Control Without Bypass Priority Ramp Lanes, No Diversion

		Percent Change from the base case	
		Short-term Diversion	Longer-term Diversion
Travel Time	veh-hr	-2	-1
	pass-hr	-3	-2
Fuel Consumption	gal.	1	1
HC	kg	0	1
CO	kg	1	2
NOX	kg	9	9

FIGURE VI-12

Effects of Short- and Longer-term Diversion for Ramp Control Without Priority Entry

The second metering scheme permits priority entry at each ramp for vehicles with three or more occupants. This implies a shoulder or second lane at each on-ramp for use by priority vehicles to bypass queued non-priority vehicles and gain unrestricted access to the freeway. The revised metering scheme with no diversion is shown in Figure VI-13. It is virtually identical to Figure VI-10. The impacts for each state of diversion are shown on Figure VI-14. A fourth type of diversion--mode shift--is included here. In the previous example, no mode shift was likely because of the equal effects on all modes of the metering scheme. However, priority entry yields further benefits for transit and shared-ride users, at the expense of low-occupancy autos and trucks. Thus, some kind of modal effect is certain. As Figure VI-14 shows, the predicted modal effect is very small. In fact, the overall difference in fuel consumption and emissions between the non-priority and priority cases is very small. The travel time savings, however, are much higher because it is high occupancy vehicles which benefit from this strategy.

Several other results from this analysis are of particular note. The priority entry scheme also was analyzed for 2+ occupant vehicles, with further improvement in most of the impact measures (see Figure VI-15). The same analysis was redone without consideration of equity among ramps, yielding a marked improvement in all categories except NOX emissions. Thus the practical need to distribute the negative effects of ramp metering geographically appears to be significant constraint on environmental and energy benefits.

TIME SLICE		ON-RAMP NUMBERS						
		2	3	4	6	7	8	9
3 4:00 - 4:15 PM	Metering Rate (vph)	180	194					835
	Queued Vehicles (veh)	20	112					9
	Diverted Vehicles (veh)	0	0					0
4 4:15 - 4:30 PM	Metering Rate (vph)	248				357	180	
	Queued Vehicles (veh)	30				15	28	
	Diverted Vehicles (veh)	0				0	0	
5 4:30 - 4:45 PM	Metering Rate (vph)	180	404	653	180	180	270	900
	Queued Vehicles (veh)	42	141	44	31	90	62	42
	Diverted Vehicles (veh)	0	0	0	0	0	0	0
6 4:45 - 5:00 PM	Metering Rate (vph)			826	180	447	270	900
	Queued Vehicles (veh)			34	47	65	87	108
	Diverted Vehicles (veh)			0	0	0	0	0
7 5:00 - 5:15 PM	Metering Rate (vph)			356	180	420	180	
	Queued Vehicles (veh)			123	63	77	121	
	Diverted Vehicles (veh)			0	0	0	0	

Legend:

On Ramp 2 is Powell Street
3 is Ashby Avenue
4 is University Avenue

On-Ramp 6 is Pierce Street
7 is Central Avenue
8 is Carlson Avenue

On-Ramp 9 is Cutting Boulevard

FIGURE VI-13

Eastshore Freeway Ramp Control Summary: Priority Ramp Bypass for Vehicles with Three Or More Occupants, No Diversion

		Percent Change from the base case			
		no diversion	short-term diversion	longer-term diversion	model shift
Travel Time	veh-hr pass-hr	-1 -4	-3 -6	-3 -5	-3 -5
Fuel Consumption	gal	1	1	1	1
HC	kg	2	0	1	0
CO	kg	3	1	2	1
NOX	kg	8	8	9	9

FIGURE VI-14

Effects of Ramp Control with Priority Entry for Vehicles with Three or More Occupants

		Percent Change from the base case	
		Equity	No Equity
Travel Time	Veh - hr	-4	-6
	pass - hr	-6	-7
Fuel Consumption	gal	1	0
HC	kg	0	-2
CO	kg	0	-1
NOX	kg	9	9

FIGURE VI-15

Effects of Ramp Control After Diversion and Model Shift With Priority Entry for Vehicles with Two or More Occupants

G. Interpretation of Results

This entry control analysis and the FREQ6PE model in general must be viewed in light of theoretical and empirical limitations, including:

- Vehicle emission estimates are based on the EPA modal emissions model and reflect a vehicle fleet without current emission control devices. Although this should not radically affect the percentage changes, future applications should be preceded by an update of the emissions models. This also is true of the fuel consumption model.
- Parallel route traffic is computed assuming all traffic diverts to a simulated single arterial. In practice, the diversion is likely to occur on many routes, so the resulting arterial congestion may be less than for a single route. The probable implication is that the estimates of arterial impedence are high, and actual costs under field conditions may be less.
- No buses are present at freeway on-ramps in the Eastshore Freeway Corridor; therefore, only mode shift to carpools is simulated. In other operating environments, where buses are present, larger mode shifts may occur. Again, the implication is that the analysis results may be slightly conservative.
- All entry control results assume no change in temporal or total demand. The effect of temporal demand shifts due to entry control are very difficult to estimate. As the total demand level increases, however, it is possible that greater benefits will accrue with priority entry. This hypothesis is supported by sensitivity analyses.[1]
- All results are for entry control alone. The effects of combined TSM tactics were not evaluated. Examples of combined tactics are entry control with variable work hours, and/or entry control with parking measures.
- The analysis did not consider potential accident and/or safety improvements which may be significant.
- Enforcement and bypass lane construction costs were not considered because of their highly site-specific nature.

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[1] Jovanis, et al., op.cit.

CASE STUDY VII

AREAWIDE ANALYSIS OF TRAFFIC ENGINEERING MEASURES

CASE STUDY VII: AREAWIDE ANALYSIS OF TRAFFIC ENGINEERING MEASURES[1]

A. Problem Presentation

The central sections of radial freeways in a medium-sized Midwestern city experience recurring congestion during peak travel periods. Most of the arterials in the central city have heavy traffic flows throughout the day, with congestion becoming severe during the peak periods in many locations. Although the area has a relatively extensive network of interconnected traffic signals, during recent years not enough attention has been given to maintaining timing plans which reflect the current pattern of traffic flow. Consequently, delays to traffic occur throughout the day because of inefficient signal operation.

Air quality is a major concern in the area, as it experiences some of the worst air pollution conditions in the nation. A majority of the HC and CO pollutants in the region's air are attributable to automobile travel. The local Metropolitan Planning Organization (MPO) is in the process of evaluating transportation measures for inclusion in the 1982 SIP revision submittal. A variety of measures are being evaluated, including actions to improve traffic flow. There is concern however, that these actions may encourage additional travel and, thus, more severe air pollution (as well as increased fuel consumption).

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[1] Adapted from Wagner, Frederick A., Urban Transportation Energy Conservation Vol. IV: Analysis of Traffic Engineering Actions, prepared under subcontract to Cambridge Systematics, Inc. for the U.S. Department of Energy, September 1978.

B. Proposed Transportation Measures

Three major types of traffic engineering action are being evaluated:

1. Freeway surveillance and control utilizing ramp metering to manage the demand entering congested sections of freeways. This action applies only during peak periods and only for congested zones of the freeway system.
2. Optimization of traffic signal timing to make the most efficient use possible of the existing traffic signal system. This action is a continuing effort requiring periodic measurements of traffic patterns in the signalized network and computation of corresponding optimum timing plans for different periods of the day either through manual or computerized techniques. This action is applicable to the entire system of surface arterial highways, both within and outside of congested zones.
3. Implementation of improved master control systems for the signalized network. This usually entails providing real-time computer control systems to allow a more flexible range of timing plans and/or traffic-responsive control algorithms which select or adjust signal timing based on actual fluctuations of traffic patterns. Such systems are most applicable within congested zones and on major access routes to high-activity centers, rather than areawide. Ultimately, such systems might be implemented throughout the arterial system, but for short to medium term planning

purposes, the more limited application is more realistic to achieve.

Each of these measures will improve the flow of traffic on the highway sections to which they are applied, thereby decreasing average travel times and per-mile fuel consumption and emissions rates for autos. Each may tend to encourage additional auto travel in the region as well, prompting concern about their efficacy in addressing environmental protection and energy conservation objectives. An analysis technique sensitive to both the supply and demand impacts of the proposed measures is requred in order to evaluate the degree to which they support efforts to improve air quality in the region.

C. Selection of Analysis Technique

The manual areawide traffic engineering analysis method (3.1.3)[1] combined with the emissions worksheets (4.1) are chosen for application to the evaluation of the proposed measures. Several aspects of the evaluation point to the use of these techniques:

- Both supply and demand impacts must be considered. The manual sketch planning technique includes estimation of the increase in auto travel associated with improved traffic flow as well as travel time and fuel consumption impacts.
- The concepts to be evaluated are not developed in detail. Specific locations or highway facilities have not been identified as candidates for any of the proposed actions. A general assessment of the areawide impact of the implementation of these improvements where appropriate is desired.
- An analysis of three distinct measures is required within a limited budget. Based on the general assessment of the effectiveness of the measures, more detailed studies may be conducted later. An inexpensive approach, able to use

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[1] The section numbers following specified analysis methods refer to the location of their description in Volume I.

available data is required, suggesting the use of a manual technique.

- The Manual Emissions Worksheets can interface directly with the manual traffic engineering analysis technique and yield accurate estimates of changes in HC, CO and NO_x emissions.

D. Overview of Analysis

The analysis is carried out in a well-defined sequence of steps as shown below. As with the other manual techniques described in this volume, a primary component of the analysis is market segmentation. In this case, different highway facility types, or functional classes, provide the basis for segmenting the areawide travel market, as noted in Step 1. The impact of the proposed traffic engineering actions is estimated separately for each highway functional class. The results are then aggregated to develop estimates of the areawide impact of each action. Work and non-work travel are also analyzed separately, with the overall impact being determined by combining the results of the separate analyses.

The steps involved in the areawide analysis of traffic engineering measures are:

1. Segment the total highway network into relatively homogeneous functional classes characterized by varying values of travel time per mile, and travel time elasticity.
2. Estimate the proportion of areawide VMT using each functional highway class.
3. Estimate the average travel time per mile for each functional highway class, and areawide average travel time.
4. For each proposed traffic engineering action, estimate the fraction of each highway class affected by the action.

5. For each proposed traffic engineering action, estimate the proportional shift in travel time caused by the action.

6. For all actions combined, estimate the proportional shift in travel time on each functional class of highway, the resulting new travel time on each highway class, and the new areawide travel time.

7. Compute the areawide proportional shift in travel time caused by the combined traffic engineering actions.

8. Estimate the elasticity of travel time for each functional highway class, and the areawide elasticity of travel time to changes in VMT.

9. Estimate the areawide elasticity of VMT to changes in travel time.

10. Estimate the proportional change in areawide VMT, at the new equilibrium point resulting from traffic engineering actions.

11. Estimate the proportional change in areawide travel time at the new equilibrium point resulting from the traffic engineering actions.

12. Estimate the elasticity of fuel consumption rate to changes in travel time.

13. Estimate the proportional change in areawide fuel consumption caused by the traffic engineering actions.

14. Compute the combined work and non-work impacts on VMT, travel time, and fuel consumption. (Steps 1-13 are repeated for work and non-work travel.)

15. Estimate the proportional change in auto emissions using the manual emissions worksheets.

E. Input Data Development

Steps 1, 2 and 3 involve setting up the analysis and acquiring base input data on the characteristics of auto travel in the urban area. These steps are described in detail below.

Step 1: Segment the Total Highway Network Into Functional Classes

As described above, the concept of travel segmentation is used in the manual traffic engineering analysis procedure. Travel in the urban area is subdivided into the following five functional classes of highway facilities:

1. Smooth flow sections of freeways
2. Congested or queued zones of freeways
3. Line-haul sections of arterial streets carrying mainly through traffic where conditions result in higher speed operation than on congested zone arterials
4. Congested zone sections of arterial streets where physical, traffic control, land use intensity, and traffic demand levels result in slow speed traffic operation (mainly located in high-employment centers)
5. Local streets, off the major arterial system, which mainly provide access to residential land uses

Segmentation of travel into these classifications aids in the analysis of potential impacts of traffic engineering actions in several ways:

- Determination of average travel time for each segment permits a more systematic estimate of average travel time for the total network either under existing conditions or under modified conditions impacted by the application of various traffic engineering actions.
- Segmentation of VMT into the proportions occurring on each functional class provides a mechanism for estimating what portion of VMT is affected by any given engineering action.
- Specification of travel time elasticities to changes in VMT for each functional classification permits estimation of this elasticity for the whole network.

The degree to which travel in the area could be segmented was controlled by the availability of data for the highway functional classes which are identified by the segmentation scheme.

Steps 2 and 3 describe the data required for each functional class of highway.

Step 2: Estimate the Proportion of Areawide Work and Non-Work VMT Using Each Functional Highway Class, P_{v_i}

With respect to VMT on freeway segments, it is assumed that all freeway traffic operates in the smooth flow regime for non-work travel, but that some portions of the freeway operation are in the congested regime during work travel periods. Separation of total freeway work trip travel, P_{v1+2}, into its two components requires knowledge of the overall average freeway travel time per mile, t_{1+2}, plus assumed values of travel time for the smooth flow and congested flow components, t_1 and t_2. Based on data from other cities, $t_1 \cong 1.3$ and $t_2 \cong 3.5$ minutes per mile. Then:

$$P_{v2} = P_{v1+2} = \left(\frac{t_{1+2} - 1.3}{3.5 - 1.3} \right)$$

$$P_{v1} = P_{v1+2} \; P_{v2}$$

For the urban area under study, the U.S. DOT's 1974 National Transportation Report, Urban Data Supplement, gives the following information:

	Proportion of Total VMT
Freeway	0.22
Arterial	0.71
Local	0.07

For work travel, the freeway portion of this data is further subdivided:

$$t_{1+2} = 1.45 \text{ minutes per mile}^1$$

$$P_{v2} = P_{v1+2} \left(\frac{t_{1+2} - 1.3}{3.5 - 1.3} \right)$$

$$= 0.22 \left(\frac{1.45 - 1.3}{2.2} \right) = 0.015$$

$$P_{v1} = 0.22 - 0.015 = 0.205$$

The estimate of the portion of arterial VMT in congested zones presented a more difficult problem since an areawide inventory of travel time was needed to do this precisely. However, it was hypothesized that a substantial portion of the congested arterial sections are in CBD areas and the remainder are found in a few other high-activity centers in the urban area.

Complete traffic count data was available for the CBD as part of the ongoing traffic engineering program of the region's central city. This data was used to estimate VMT in the CBD. It was found that CBD VMT equaled approximately 2 percent of the areawide total. Assuming that the CBD accounts for about half the total areawide congested zone traffic, the estimate of the portion of VMT in congested zones was raised to 4 percent

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[1] This value was obtained from UTPS highway network model validation runs, conducted as a standard aspect of the urban area's ongoing transportation planning process.

of arterial VMT or $4 \cdot 0.71) \cong 3$ percent of areawide total VMT.

The following breakdown of work and non-work VMT into the five highway functional classes emerged from this analysis:

Functional Class, i		Work P_{v_i}	Non-Work P_{v_i}
1.	Smooth flow freeways	0.205	0.222
2.	Congested zone freeways	0.015	0
3.	Line-haul arterials	0.68	0.68
4.	Congested zone arterials	0.03	0.03
5.	Local streets	0.07	0.07

Step 3: Estimate the Average Travel Time per Mile for Each Functional Highway Class, t_i, and Areawide, t

The t_i values for the individual functional highway classes were estimated as follows:

- For cases where all freeways are operating with smooth flow, e.g. during non-work travel periods, the following relation was assumed:[1]

$$t_1 = 1.1 + 0.2 \frac{V}{C}$$

where:

$\frac{V}{C}$ = the average volume to capacity ratio for all freeways

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[1] These assumptions are based on empirical evidence from a number of cities. See Wagner, Frederick A., Urban Transportation Energy Conservation, Volume IV: Analysis of Traffic Engineering Actions, prepared under subcontract to Cambridge Systematics Inc. for the U.S. Department of Energy, September 1978.

- For congested (queued up) zones of freeways it was assumed that

$$t_2 \cong 3.5$$[1]

- As shown in Step 2, above, composite freeway travel time during peak periods, t_{1+2}, is used to estimate the proportion of VMT operating in the smooth flow regime, P_{v1}, and in the congested flow regime, P_{v2}. The composite freeway travel time needed in this computation can be obtained from available freeway performance data, from new samples of travel time on representative sections of freeway, or by using freeway flow simulation models to estimate existing conditions. In this case, freeway flow simulation was used to estimate t_{1+2}.
- For general arterials and congested zone arterials, estimate t_3 and t_4 from available travel time data or from new samples of travel time data collected on a representative sample of routes. (Alternatively, use street traffic flow simulation models to estimate t_3 and t_4 for representative routes or zones of the network).
- For local streets, estimate t_5 from available data or from small samples in representative neighborhoods.

For this urban area, substantial peak period travel time data were available. Table VII-1 summarizes the analysis and interpretation of the available data to obtain estimates of t for different functional highway classes:

The basic results are:

Functional Class, i	Work Travel t_i	
1	1.3	1.45
2	3.5	
3		2.83
4		4.11
5		3.0

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[1] See footnote on previous page.

TABLE VII-1

Peak Period Travel Times

Functional Type	Location	Average Speed, Mph	Average Travel Time, Min/Mile	Length of Routes
Congested Zone	CBD	14.6	4.11	--
General Arterial	South Corridor	21.0	2.86	5.0
	East Corridor	19.2	3.13	33.2
	West Corridor	22.8	2.63	48.4
Average for General Arterials:*		21.2	2.83	86.6 Total
Freeways	East Corridor	30.5	1.97	7.8
	West Corridor	43.5	1.38	8.0
	Central EB	48.4	1.24	9.0
	Central WB	48.4	1.24	9.0
	North Corridor	36.6	1.64	6.0
	South Corridor	47.6	1.26	6.0
Average for Freeways:*		41.5	1.45	45.8 Total

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*Average values weighted by the lengths of test routes.

Given the values of t_i and P_{vi} for individual functional highway classes, areawide average travel time, t, is estimated by:

$$t = \sum_i P_{vi}\ t_i$$

For this urban area,

$$t = 2.58 \text{ minutes per mile, or } 23.3 \text{ mph}$$

The travel time characteristics for non-work travel are significantly different than for work travel since the preponderance of non-work trips are made outside of peak periods. No substantive field data were available for off-peak travel, hence, it was necessary to base non-work travel time estimates on the following set of assumptions:

- The distribution of VMT by highway class for non-work travel is the same as for work travel
- Negligible freeway congestion is encountered by non-work travel. Therefore, average freeway travel time was assumed to be 1.2 minutes per mile (50 mph) - all in the smooth flow regime.
- For travel on local streets, it was assumed that work and non-work travel times per mile are equal since local streets are so sparsely loaded.
- For arterial streets, it was assumed that an average elasticity of travel time of 0.17 could be used to estimate the difference between non-work period and work period travel times.[1] Assuming that hourly traffic volumes during non-work trip periods are 40 percent lower than during work trip periods, then average travel times should be approximately $40(0.17) \cong 7$ percent lower for non-work trips.

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[1] See Wagner, op. cit. for a discussion of the basis for this assumption.

These assumptions yield the following estimates of t_i for non-work travel:

Functional Class, i	Non-Work Travel t_i
1	1.2
2	-
3	2.63
4	3.82
5	3.00

These data plus the P_{vi} values for non-work travel from Step 2 can then be used to calculate areawide average travel time, t, for non-work travel. For this urban area,

$$t = 2.38 \text{ minutes per mile, or } 25.2 \text{ mph}$$

F. Description of Analytical Procedure

Steps 4 through 14 involve the application of the manual traffic engineering analysis method. These steps are described below.

Step 4: For Each Proposed Traffic Engineering Action j, Estimate the Fraction of Each Functional Highway Class Affected by the Action F_{ij}

This step defines where in the highway network an action is implemented, or in other words, what portion of VMT within an individual highway class is affected by a particular action. This permits an accurate representation of actions that are designed for specific subareas or corridors, as well as those which are applied throughout the area on all highways of a given functional class. The three proposed traffic engineering actions were assumed to apply to the highway network as follows:

1. Freeway surveillance and control was assumed to be implemented on all congested zones of the freeway system. Therefore, the incidence of this action is represented by setting $F_{21} = 1.00$.

2. Optimization of traffic signal timing is assumed to be undertaken for the entire system of surface arterials both within and outside of congested zones (i.e., for functional highway classes 3 and 4). The incidence of this action is represented by setting $F_{32} = 1.00$ and $F_{42} = 1.00$.

3. Implementation of improved master control systems for the signalized network was assumed only within congested zones and in other high activity centers initially. The incidence of this action is represented in approximate form by setting: $F_{33} = 0.5$ and $F_{43} = 1.00$. In other words, the action is conservatively assumed to apply to all congested zone arterial traffic and to half the remaining arterial VMT.

Step 5: For Each Proposed Traffic Engineering Action j, Estimate the Proportional Shift in Average Travel Time on Affected Locations, F_{ij}, Caused by the Action, $PS_{t_{ij}}$

This impact is defined as the shift in average travel time that would occur under given fixed levels of VMT on those portions of the highway network where an action is applied. Estimates of $PS_{t_{ij}}$ may be made based on observed impacts resulting from the same type of action implemented in other places (e.g., either other locations in the same urban area or in some other similar urban areas). Tables VII-2, VII-3, and VII-4, for example, summarize the impacts of traffic signal system projects and freeway traffic control projects in several cities, and provide estimates of the order of magnitude of $PS_{t_{ij}}$ for these actions.

Table VII-2 summarizes impacts of traffic signal timing efforts in several cities encompassing a wide range of types of surface arterial highways. The impact averages approximately 12 percent - a figure used for this analysis. Alternatively, recent retiming projects could have been used as examples of the potential of this action in the urban area if accurate before and after data on travel speeds were available.

Table VII-3 summarizes the impacts of various projects in which the master control system for traffic singals was upgraded. The size of the impact is strongly dependent on the base condition of the traffic control system. Data in this figure are organized into four sets which vary with respect to the base conditions. The average impact for each set is summarized below:

	Base Condition	$PS_{t_{ij}}$
1.	Fully or Partially Non-Interconnected Signals with Old Timing Plans	-0.32
2.	Interconnected Signals with Single Dial Master Control and Old Timing Plans	-0.17
3.	Non-Interconnected Signals, with Traffic Activated Control of Individual Signals	-0.12
4.	Interconnected Signals with Three Dial Master Control and Actively Managed Timing	-0.06

The base conditions in the metropolitan area under study are fairly well advanced and are most accuratedly represented by 4, above. Therefore, the impacts of improved master control of traffic signals is estimated at $PS_{t_{ij}} \cong 0.06$, a 6 percent improvement

TABLE VII-2

Traffic Signal Timing Optimization Impacts

Location	Number of Intersections	Study Method	Time of Day	Average Speed, Mph		
				Before	After	Percent Change
Toronto Central Area	68	Field Measurement	7-9	15.8	16.5	+ 4.4
			10-12	17.1	17.5	+ 2.3
			1-3	15.5	16.3	+ 5.2
			4-6	13.7	13.7	0
Toronto Suburban Area	51	Field Measurement	7-9	21.3	21.0	- 1.4
			10-12	28.2	29.1	+ 3.2
			1-3	27.5	28.1	+ 2.2
			4-6	21.7	20.9	- 3.7
San Jose - CBD	46	TRANS Simulation	4-6	15.4	15.7	+ 1.9
Los Angeles - Inner City (Broadway - Figueroa)	26	TRANS Simulation	~~3-4~~ 5:30-6	17.4	20.6	+21.1
			4-5:30	15.4	18.9	+22.7
Los Angeles - Inner City (Pico Boulevard)	6	TRANS Simulation	2:30-3:30	21.1	24.9	+18.0
			4:30-5:30	20.2	21.5	+ 6.4
Los Angeles - Inner City (Wilshire Boulevard)	45	TRANS Simulation	AM Peak	13.1	14.4	+ 9.9
Macon, Georgia CBD	54	SIGOP Simulation	7:45-8:45	12.7	14.4	+13.4
			4:45-5:45	11.7	13.7	+17.1
Inglewood, California Citywide	60	SIGOP Simulation	7-10	22.9	30.9	+35.0
			3-6	22.0	30.0	+36.0
Montgomery, Alabama CBD	50	TRANSYT Simulation	AM Peak	16.31	20.24	+24.1
			Off Peak	19.09	20.26	+ 6.1
			PM Peak	17.94	19.87	+10.8
Charlotte, NC CBD Fringe	10	TRANS Simulation	5-6	7.68	8.66	+25.8
Washington, DC CBD	40	UTCS-1 (NETSIM)	Off Peak	11.97	13.22	+10.4
Average, All Locations:						+11.8
Average, Toronto & San Jose						+ 1.6
Average, All Others:						+18.4

Note: Toronto and San Jose were aggressively managed, computerized signal systems in the BEFORE case

Source: Wagner, op. cit.

TABLE VII-3

Impacts of Traffic Signal Master Control Improvements

Nature of Master Control System Improvement	Location	Time of Day	Percent Improvement In Speed Or Travel Time
Fully or Partially Non-Interconnected Signals with Old Timing Plans Versus Interconnected Signals, Advanced Master Control, and Optimized Signal Timing	Columbus, Georgia CBD	Pre-AM Peak	49
		AM Peak	34
		Off Peak	40
		Pre-PM Peak	22
		PM Peak	32
	New York City:		
	Northern Boulevard	Peak	34
	Hillside Avenue	Peak	39
	Union Turnpike	Peak	26
	Roosevelt Avenue	Peak	32
	Thunder Bay, Ontario CBD	AM Peak	19
		Off Peak	20
		PM Peak	8
	Group Average		32
Interconnected Signals, Single Dial Master Control, Old Timing Plans Versus Interconnected Signals, Computerized Master Control, Optimized Timing	Charleston, SC CBD	AM Peak	12
		AM Off Peak	16
		PM Off Peak	20
		PM Peak	21
	Raleigh, NC CBD	AM Peak	6
		Off Peak	12
		PM Peak	12
	Raleigh, NC Arterials	AM Peak	30
		Off Peak	10
		Pm Peak	39
	*San Jose, Costs Rica CBD	All times of Day	13
	Group Average		17

TABLE VII-3 (continued)

Nature of Master Control System Improvement	Location	Time of Day	Percent Improvement In Speed Or Travel Time
Non-Interconnected Signals with Traffic Actuated Controllers Versus Interconnected Signals, Computerized Master Control, and Optimized Signal Timing	West London, England	Peak	9
	Glasgow, Scotland	AM Peak Mid-day PM Peak	12 9 18
	Group Average		12
Interconnected Signals, Three or More Dial Control (Minimum of Three Timing Plans), Actively Managed Timing Versus Interconnected Signals, Computerized Master Control, and Optimized Timing Plans	San Jose, CA - CBD	Peak	5
	Wichita Falls, TX	Peak	10
	Washington, DC - CBD	AM Peak Off Peak PM Peak	5 6 8
	*San Diego, CA - CBD	7 Hrs., Peak and Off Peak	2
	Stockholm, Sweden	Peak	7
	*San Jose, Costa Rica	All Times of Day	8
	Group Average		6

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*Estimated by traffic simulation methods.

Source: Wagner, op. cit.

in mean travel time.

Table VII-4 summarizes the impacts on average speed of major freeway traffic surveillance and control projects in six cities. The average improvement in travel speeds for free-flow and congested zones combined is approximately 20 percent. Table **VII-5** translates these results into estimates of the reduction in the proportion of the freeway which is congested. The data indicate that surveillance and control can eliminate approximately 60 percent of the congested freeway zones. In other words, of all freeway sections currently experiencing congestion (i.e., average travel time of 3.5 minutes per mile), approximately 60 percent could be upgraded to smooth-flow status (i.e., average travel time of 1.3 minutes per mile). Thus, the proportional shift in travel time for all currently congested freeway zones is:

$$PS_{t_{ij}} = 0.60 \left(\frac{1.3 - 3.5}{3.5} \right) = -0.38 \ .$$

Alternatively, instead of relying on estimates of impacts from other locations, traffic simulation models could be used to develop location specific impacts. Models are available for both signalized arterial street situations and for freeway situations. The former type of model (e.g., the UTCS-1 model and the TRANSYT model) can be used to estimate impacts of traffic signal timing optimization and master control system improvement. The latter type (e.g., the FREQ model) can be used to estimate the impacts of freeway ramp control systems.

TABLE VII-4

Freeway Ramp Control System Impacts on Average Speed

Location	Length, Miles	Time of Day	Before Ramp Control	After Ramp Control	Percent Difference vs. Before	After, Including Ramp Delays	Percent Difference vs. Before
Minneapolis I-35W							
Northbound	16.6	7:15-8:15	33.8	45.5	34	43.0	27
(Inbound)	16.6	6:30-9:00	43.9	50.1	14	48.5	10
Southbound	12.7	4:30-5:30	33.7	40.1	19	38.6	15
(Outbound)	12.7	3:3—6:30	38.5	45.7	19	44.4	15
Chicago, Eisenhouwer Expressway							
Eastbound	9.4	2 hour AM Peak	30.3	33.0	9		
(Inbound)	9.4	4 Hour AM Peak	37.7	39.7	5		
Los Angeles, Santa Monica Freeway Eastbound (Inbound)	13.5	6:30-9:30	36.2	50.6	40	41.4	14
Houston, Gulf Freeway Northbound (Inbound)	6	7:00-8:00	20.4	32.6	60		
Los Angeles Harbor Freeway							
Southbound	4	3:45-6:15	25.9	40.3	55	37.4	44
(Outbound)	4	3:45-6:15	25.9	40.3	55	37.4	44
Detroit, Lodge Freeway Northbound (Outbound)	6	2:30-6:30	27.3	36.4	33	32.6	19
Averages All Data			32.8	41.4	26		
Averages for Data Including Ramp Delays			34.2			40.8	19

Source: Wagner, op. cit.

TABLE VII-5

Freeway Ramp Control System Impacts on Proportion of Freeway Minute-Miles Congested

Location	Length, Miles	Time of Day	Proportion Congested Before Ramp Control	After Ramp Control	Percent Reduction
Minneapolis, I-35W					
Northbound	16.6	7:15 - 8:15	.25	.05	80
(Inbound)	16.6	6:30 - 9:00	.07	0	100
Southbound	12.7	4:30 - 5:30	.25	.13	48
(Outbound)	12.7	3:30 - 6:30	.16	.05	69
Chicago, Eisenhower Expressway					
Eastbound	9.4	2 Hr. AM Peak	.34	.27	21
(Inbound)	9.4	4 Hr. AM Peak	.17	.135	21
Los Angeles, Santa Montica Freeway Eastbound (Inbound)	13.5	6:30 - 9:30	.20	0	100
Houston, Gulf Freeway Northbound	6	7:00 - 8:00	.76	.28	63
Los Angeles, Harbor Freeway Southbound (Outbound)	4	3:45 - 6:15	.49	.13	73
Detroit, Lodge Freeway	6	2:30 - 6:30	.43	.20	53
Northbound (Outbound)	6	2:30 - 6:30	.43	.20	53
Averages			.31	.12	61

Source: Wagner, op. cit.

Step 6: For All Actions Combined, Estimate the Proportional Shift in Travel Time on Each Functional Class of Highway, PS_{t_i}, the Resulting New Travel Times of Each Highway Class, t_{n_i}, and the New Areawide Average Travel Time, t_n

These estimates are calculated as follows: first, for each functional highway class, the impact of the combined actions is,

$$PS_{t_i} = [(1 + F_{i1}\ PS_{ti1})(1 + F_{i2}\ PS_{ti2})\ldots(1 + F_{in}\ PS_{tin})] - 1$$

and

$$t_{n_i} = t_i\ (1 + PS_{ti})$$

For the areawide network, the new average travel time is

$$t_n = \sum_i P_v\ t_{ni}$$

The intermediate results for steps (1) through (6) are summarized in Table VII-6 which represents work travel characteristics in the urban area.

Step 7: Compute the Areawide Proportional Shift in Average Travel Time Caused by the Combined Traffic Engineering Actions, PS_t

This is the proportional shift in travel time that would occur if VMT were held constant; in other words, the proportional shift in the supply curve. A simple proportion change equation is applied to the original travel time, t, and the new travel time, t_n, as follows:

TABLE VII-6

Worksheet for Steps 1-6, Work Travel

Step(1)	Step(2)	Step(3)	Step(4)		Step(5)	Step(6)	
Functional Class, i	P_{v_i}	t_i	Action j	F_{ij}	$PS_{t_{ij}}$	PS_{t_i}	t_{n_i}
1. Smooth flow freeway	.205	1.3					1.3
2. Congested zone freeway	0.015	3.5	1	1.00	-0.38	-0.38	2.17
3. General arterial	0.68	2.83	2	1.00	-0.12		
			3	0.50	-0.06	-0.146	2.42
4. Congested zone	0.03	4.11	2	1.00	-0.12	-0.173	3.40
			3	1.00	-0.06		
5. Local street	0.07	3.00					3.00
		$t = 2.58$					$t_n = 2.26$

$$PS_t = \frac{t_n - t}{t}$$

In this case,

$$PS_t = \frac{2.26 - 2.58}{2.58} = -0.124$$

Step 8: Estimate the Elasticity of Travel Time to Changes in VMT for Each Functional Highway Class, e_{t_i}, and for the Area-wide Highway Network, e_t

The value e_t represents the degree to which travel speeds or travel time rates degrade with additional traffic volume. Guidelines for typical e_{t_i} values observed in practice are summarized below:[1]

- For non-work travel (off-peak periods)
  - Freeways - Assume all sections of freeway operate in the smooth flow regime.

    $$e_{t_i} \cong 0.16 \frac{V}{C}$$

    where V/C = the average volume to capacity ratio during offpeak periods. A reasonable V/C = 0.5, so $e_{t_i} \cong 0.08$.
  - General arterials and arterials in congested zones

    $$e_{t_3} \cong 0.17$$

    $$e_{t_4} \cong 0.17$$
  - Local streets

    $$e_{t_5} \cong 0$$

    Since traffic volumes are very light.

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[1] For a detailed discussion of the development of e_{t_i} estimates, see Wagner, op.cit., Chapter II.

- For work travel (peak periods)

  - Freeways - Assume at least some portion of the freeway system is congested. Then e_{t1+2}, the travel time elasticity for all freeway sections combined, ranges from approximately 2 to 4, depending on the severity of existing congestion, as shown below.

Average Freeway Travel Time for All Sections, t_{1+2}

Range of t_{1+2}	Midpoint of t_{1+2}	Elasticity of Travel Time, e_{t1+2}
1.37 - 1.52	1.445	2.12
1.52 - 1.78	1.65	3.39
1.78 - 2.17	1.95	4.43

In this urban area, since

$$t_{1+2} = 1.45,\ e_{t_{1+2}} \cong 2.1$$

  - General arterials

$$e_{t_3} \cong 0.17$$

  - Congested zone arterials

$$e_{t_4} \cong 1.37$$ (observed range of e_{t_4} from 0.56 to 2.82)

  - Local streets

$$e_{t_5} \cong 0$$

The estimates of travel time elasticities for individual highway classes are summarized in Table VII-7.

Alternatively, freeway and street traffic simulation models can be used to estimate e_{t_i} for specific highway situations.

TABLE VII-7

Travel Time Elasticities

Functional Class, i	P_{v_i}	Work e_{t_i}	Non-Work e_{t_i}
1. Smooth flow freeways 2. Congested zone freeways	0.22	2.12	0.08
3. General arterials	0.68	0.17	0.17
4. Congested zone arterials	0.03	1.00	0.17
5. Local Streets	0.07	0	0
Areawide		$e_t = 0.612$	$e_t = 0.14$

Simulation models are powerful in this regard since VMT can be varied at will by specific amounts, upward or downward, holding all other variables constant, and e_{t_i} computed from the simulation output.

After estimating e_{t_i} for individual highway segments, the areawide e_t can be computed by

$$e_t = \sum_i P_{v_i} e_{t_i}$$

Notice that the two freeway segments are combined in this step, i.e.

$$e_t = P_{v1+2} e_{t1+2} + P_{v3} e_{t3} + P_{v4} + P_{v5} e_{t5}$$

The computed e_t values are also shown in Table VII-7.

Step 9: Estimate the Areawide Elasticity of VMT to Changes in Travel Time, e_v

The value e_v represents the sensitivity of the volume of auto travel to changes in travel time rate or speed. Several ongoing efforts are aimed at estimating reliable values for e_v. In this study, previous applications of the disaggregate travel demand forecasting models described in Volume I were used to estimate short-range values of e_v, and yielded the following results:[1]

- Work travel, $e_v = -0.01$
- Non-work travel, $e_v = -0.15$

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[1] See Wagner, op. cit., Chapter II.

The short-range VMT elasticities come about as a result of work trip mode shifts, whereas non-work trip VMT elasticities result primarily from modified trip frequency and trip length.

Longer-range VMT elasticities are known to be higher than the short-range values since they are affected additionally by changes in land use and choice of residential location. Since a whole host of non-transportation forces, which were outside the scope of this study, significantly influence these longer range responses, sensitivity tests using various higher values of e_v were used to investigate the possible range of longer term impacts. These sensitivity tests are not described here, however.

Step 10: Estimate the Proportional Change in Areawide VMT at the New Equilibrium Point Resulting from the Traffic Engineering Actions, PC_v

This computation accounts for the interaction between supply and demand for highway facilities. Improving the level of service or travel speed on the highway network (supply) will lead to additional auto travel which offsets, to some degree, the improvement in highway level of service. The demand for and supply of highway travel (VMT and travel time rate) will eventually reach a new equilibrium point. The equilibrium change in VMT, relative to the base condition is given by :

$$PC_v = PS_t \left(\frac{e_v}{1 - e_v e_t} \right)$$

Results for this urban area are given on worksheets in Tables VII-8 and VII-9, and are summarized in Table VII-10.

Step 11: Estimate the Proportional Change in Areawide Average Travel Time at the New Equilibrium Point Resulting from the Traffic Engineering Actions, PC_t

This also accounts for supply-demand interaction and is computed by:[1]

$$PC_t = PS_t \left(\frac{1}{1 - e_v e_t} \right)$$

Results for this computation also are shown on worksheets in Tables VII-8, VII-9, and VII-10.

Step 12: Estimate the Elasticity of Fuel Consumption Rate Per Mile to Changes in Travel Time, e_F

Research shows that e_F is a function of the base condition areawide travel time, t. For the 1976 VMT weighted mix of vehicles in the U.S. fleet:[1]

$$e_F = \frac{0.0201t}{0.085 - 0.201t}$$

In this case,

- Non-work travel, $t = 2.38$, $e_F = 0.360$
- Work travel, $t = 2.58$, $e_F = 0.379$

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[1] See Wagner, op. cit. for derivations of these relationships

TABLE VII-8

Worksheet for Steps 1-13, Work Travel

Step(1) Functional Class, i	Step(2)	Step(3)	Step(4)		Step(5)	Step(6)		Step(8)
	P_{v_i}	t_i	Action j	F_{ij}	$PS_{t_{ij}}$	PS_{t_i}	t_{n_i}	e_{t_i}
1.	0.205	1.3					1.3	2.12
2.	0.015	3.5	1	1.00	-0.38	-0.38	2.17	
3.	0.68	2.83	2 3	1.00 0.50	-0.12 -0.06	-0.146	2.42	0.17
4.	0.03	4.22	2 3	1.00 1.00	-0.12 -0.06	-0.173	3.40	1.00
5.	0.07	3.00					3.00	0
	$t = 2.58$					$t_n = 2.26$		

Step (7) $PS_t = \frac{t_n - t}{t} = \frac{2.26 - 2.58}{2.58} = -0.124$

Step (8) $e_t = \sum_i PV_i e_{t_i} = 0.612$

Step (9) $e_v = -0.01$

Step (10) $PC_v = PS_t\left(\frac{e_v}{1-e_v e_t}\right) = -0.124\left(\frac{-.01}{1 + .01\ (.612)}\right) = -0.0012$

Step (11) $PC_t = PS_t\left(\frac{1}{1-e_v e_t}\right) = -0.124\left(\frac{1}{1 + .01\ (.612)}\right) = -0.123$

Step (12) $e_F = \frac{0.0201t}{0.085 + 0.0201t} = \frac{0.0201\ (2.58)}{0.085 + 0.0201\ (2.58)} = 0.379$

Step (13) $PC_F = (1 + PC_v)\ (1 + e_F PC_t) - 1 = (1.0012)\ (0.9534 - 1) = -0.045$

TABLE VII-9

Worksheet for Steps 1-13, Non-Work Travel

Step(1) Functional Class, i	Step(2)	Step(3)	Step(4)		Step(5)	Step(6)		Step(8)
	P_{v_i}	t_i	Action j	F_{ij}	$PS_{t_{ij}}$	PS_{t_i}	t_{n_i}	e_{t_i}
1.	0.22	1.20					1.20	0.08
2.	0	-	1	X			-	
3.	0.68	2.63	2 3	1.00 0.50	-0.12 -0.06	-0.146	2.25	0.17
4.	0.03	3.82	2 3	1.00 1.00	-0.12 -0.06	-0.173	3.16	0.17
5.	0.07	3.00					3.00	0

$t = 2.38$ $\qquad\qquad$ $t_n = 2.10$

Step(7) $\quad PS_t = \dfrac{t_n - t}{t} = \dfrac{2.10 - 2.38}{2.38} = -0.118$

Step(8) $\quad e_t = \sum_i PV_i e_{t_i} = 0.14$

Step(9) $\quad e_v = -1.015$

Step(10) $\quad PC_v = PS_t \left(\dfrac{e_v}{1-e_v e_t}\right) = -0.118 \left(\dfrac{-0.15}{1+.15(.14)}\right) = 0.017$

Step(11) $\quad PC_t = PS_t \left(\dfrac{1}{1-e_v e_t}\right) = -0.118 \left(\dfrac{1}{1+.15(.14)}\right) = -0.115$

Step(12) $\quad e_F = \dfrac{0.0201t}{0.085 + 0.0201t} = \dfrac{0.0201(2.38)}{0.085 + 0.0201(2.38)} = 0.360$

Step(13) $\quad PC_F = (1 + PC_v)(1 + e_F PC_t) - 1 = (1.017)(.9586) = -0.025$

TABLE VII-10

Summary of Impacts of Combined Traffic Engineering Actions

Travel Class	Proportion Change in Areawide VMT PC_v	 Travel Time PC_t	 Fuel Consumption PC_F
Work Travel	+0.0012	-0.123	-0.045
Non-Work Travel	+0.017	-0.115	-0.025
Work + Non-Work	+0.0112	-0.1180	-0.0324

NOTE: Traffic engineering actions tested are comprehensive combinations of (1) freeway surveillance and control, (2) traffic signal timing optimization, and (3) improvement of master traffic signal control system.

Step 13: Estimate the Proportional Change in Areawide Fuel Consumption Resulting from the Traffic Engineering Actions, PC_F

This is computed by:

$$PC_F = (1 + PC_V)(1 + e_F\ PC_t) - 1$$

Sample calculations for Steps 1 through 13 for both work travel and non-work travel are presented in Tables VII-8 and VII-9. The findings are summarized in Table VII-10.

Step 14: Compute the Combined Work Trip and Non-Work Trip Impacts on Areawide VMT, Average Travel Time, and Fuel Consumption

If F_w is the fraction of total travel that is work travel, and the subscripts "w" and "nw" are used to depict work and non-work impacts, then,

$$PC_v = F_w\ PC_{v_w} + (1 - F_w)\ PC_{v_{nw}}$$

$$PC_t = F_w\ PC_{t_w} + (1 - F_w)\ PC_{t_{nw}}$$

$$PC_F = F_w\ PC_{F_w} + (1 - F_w)\ PC_{F_{nw}}$$

In this case, $F_w = .37$.

The results for work and non-work travel combined are shown in Table VII-10.

G. Air Quality Impact Assessment

Two factors associated with the comprehensive traffic engineering improvement program will influence auto emissions in the urban area:

1. The increased average travel speeds will lower the average HC and CO emission rates and rasie the NOx emission rate.
2. The increase in auto VMT will tend to offset the effect of lower HC and CO emission rates and will further increase the total NOx emissions in the region.

The emissions worksheets (4.1) may be used to examine the relative impact of each of these factors and to estimate the net change in total auto emissions associated with the proposed traffic engineering actions.

Because areawide traffic engineering procedure used in this analysis calculates only the proportional change in VMT, rather than the absolute values of the base case and revised total VMT, an independent estimate of base case VMT and the total number of trips (or average trip length) must be obtained for work and non-work travel in the region. Previous travel demand modelling work, based on a 1971 home interview survey, provided estimates of the necessary data for 1980 and 1985. Linear interpolation was used to develop estimates for the 1982 analysis year assumed in this evaluation. Lengths for each type of trip were not necessary because both VMT and total vehicle trip estiamtes were available from the previous modelling work. The base case VMT and trip volume estimates are entered in worksheet VI-A.

The revised case VMT and trip volume may be calculated separately for work and non-work trips by applying the proportional changes in VMT shown in Table VII-10 to the base case VMT and trip volume values.[1] For example, the revised case work VMT is given by:

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[1] It is assumed that change in the number of trips in the urban area is proportional to the change in VMT.

VI-A. INPUT TRAVEL DATA SUMMARY FOR EMISSIONS ESTIMATION

☒ Base Alternative

☐ Revised Alternative

Forecast Year: ____________________

Policy: Areawide Comprehensive Traffic Engineering

Population Subgroup	Work VMT (I or IV)[1]	÷	Average Work Trip Distance (miles)(I)	=	Number of One-Way Work Trips		Non-Work VMT (I or IV)	÷	Average Non-Work Trip Distance (miles) (I)	=	Non-Work Trips
All	5,036,000		-		336,900		8,674,000		-		1,373,000
$\sum =$	5,036,000			$\sum =$	336,900	$\sum =$	8,674,000			$\sum =$	1,373,000
	TOTAL WORK VMT				TOTAL WORK TRIPS		TOTAL NON-WORK VMT				TOTAL NON-WORK TRIPS

1,709,900 TOTAL TRIPS

---

[1] Source Worksheets are indicated in parentheses where applicable. VMT and trips on worksheets I and IV in Appendix A must be multiplied by the number of households per population subgroup.

VI-A. INPUT TRAVEL DATA SUMMARY FOR EMISSIONS ESTIMATION

☐ Base Alternative
☒ Revised Alternative
Forecast Year: ____________________
Policy: Areawide Comprehensive Traffic Engineering

Population Subgroup	Work VMT (I or IV)[1]		Average Work Trip Distance (miles)(I)		Number of One-Way Work Trips	Non-Work VMT (I or IV)		Average Non-Work Trip Distance (miles) (I)		Non-Work Trips
All	5,030,000	÷	-	=	336,500	8,529,000	÷	-	=	1,350,000
$\sum =$	5,030,000		$\sum =$		336,500	$\sum =$ 8,529,000		$\sum =$		1,350,000
	TOTAL WORK VMT				TOTAL WORK TRIPS	TOTAL NON-WORK VMT				TOTAL NON-WORK TRIPS

1,686,500 TOTAL TRIPS

---

[1] Source Worksheets are indicated in parentheses where applicable. VMT and trips on worksheets I and IV in Appendix A must be multiplied by the number of households per population subgroup.

$$\begin{aligned}\text{Revised VMT} &= \text{Base VMT} \times (1 + PC_v(\text{work})) \\ &= 5{,}030{,}000\ (1 + .0012) \\ &= 5{,}036{,}000\end{aligned}$$

The revised case VMT and trip volume estimates are entered on a separate copy of worksheet VI-A.

Worksheet VI-B is used to record the base and revised case percentage of cold starts for work and non-work trips. No parking duration data was available for work or non-work travel in the region, so estimated figures for cold start trip percentages were obtained from Table D.1 in Volume I.

Worksheet VI-C is then executed twice (once each for the base and revised cases) to determine areawide start up vehicle emissions. Worksheets VI-A and VI-B and emissions Tables D.2 through D.5 provide the necessary data for the calculations. A 40-degree ambient temperature is assumed since the region experiences its highest air pollution concentrations during the winter months.

Travel (VMT) related emissions for the base and revised cases are calculated using worksheet VI-D. Both the VMT change and the change in average travel speed associated with the traffic engineering actions are considered in the calculations. The base case work and non-work average travel time rates were calculated in step 6 of the manual traffic engineering analysis procedure. These travel time rates may be converted to travel speeds with the following formula:

VI-B. COLD START FRACTIONS

☒ Base Alternative

☒ Revised Alternative

Policy: Areawide Traffic Engineering

Subgroup: All

Forecast Year: 1982

1. If Daily Parking Duration Data are Available:

% of Auto Trips by Catalyst-Equipped Vehicles (Table D.1)		% of Auto Trips with Parking Duration 1 hour		% of Auto Trips by Non-Catalyst Equipped Vehicles		% of Auto Trips with Parking Duration 4 hours		% of Auto Trips with Cold Starts
	X		+		X		=	

2. If Daily Parking Duration Data are not Available

% of Work Trip Cold Starts (Table D.2)

90

% Non-Work Trip Cold Starts (Table D.2)

57

VI-C. AUTO START-UP AND EVAPORATIVE EMISSIONS

☒ Base Alternative

☐ Revised Alternative

Policy: Areawide Traffic Engineering

Forecast Year: 1982

Temperature: 40°

Work Trips							Non-Work Trips			
(1) Population Subgroup	(2) % Cold Starts (VI-B)[1]	(3) Trips (IV-A)	Pollutant[2]	From Table[3]	(4) Start-Up Factors	(5) Emissions = Col. 3 X Col. 4 (grams)	(6) % Cold Starts (VI-B)	(7) Trips (VI-A)	(8) Start-Up Factors	(9) Emissions = Col. 3 X Col. 4 (grams)
All	90	336,500	HC(c)	D.2	14.6	4,913,000	57	1,350,000	10.31	13,919,000
			CO(c)	D.3	245.0	82,554,000			159.0	214,650,000
			NOx(c	D.4	3.5	1,178,000			3.1	4,185,000
			HC(h)	D.6	6.0	2,019,000			6.0	8,100,000
			HC(c)	D.2						
			CO(c)	D.3						
			NOx(c	D.4						
			HC(h)	D.6						
			HC(c)	D.2						
			CO(c)	D.3						
			NOx(c	D.4						
			HC(h)	D.6						

TOTALS

TOTALS $\sum$ Subgroups	Work Trip Start-Up Emissions (grams)	+	$\sum$ Subgroups	Non-Work Trip Start-Up Emissions (grams)	=	Total Start-Up Emissions (grams)
HC	6,943,000		HC	22,019,000		28,962,000
CO	82,443,000		CO	214,650,000		297,093,000
NOx	1,178,000		NOx	4,185,000		5,363,000

---

[1] Source Worksheets are indicated in parentheses where applicable

[2] (c) indicates cold start factor

(h) indicates hot soak factor

[3] both work and non-work start-up factors obtained from the indicated tables

VI-C. AUTO START-UP AND EVAPORATIVE EMISSIONS

☐ Base Alternative

☒ Revised Alternative

Policy: Areawide Traffic Engineering

Forecast Year: 1982

Temperature: 40°

	Work Trips						Non-Work Trips			
(1) Population Subgroup	(2) % Cold Starts (VI-B)[1]	(3) Trips (IV-A)	Pollutant[2]	From Table[3]	(4) Start-Up Factors	(5) Emissions = Col. 3 X Col. 4 (grams)	(6) % Cold Starts (VI-B)	(7) Trips (VI-A)	(8) Start-Up Factors	(9) Emissions = Col. 3 X Col. 4 (grams)
All	90	336,900	HC(c)	D.2	14.6	4,919,000	57	1,373,000	10.31	14,156,000
			CO(c)	D.3	245.0	82,541,000			159.0	218,307,000
			NOx(c	D.4	3.5	1,180,000			3.1	4,256,000
			HC(h)	D.6	6.0	2,021,000			6.0	8,238,000
			HC(c)	D.2						
			CO(c)	D.3						
			NOx(c	D.4						
			HC(h)	D.6						
			HC(c)	D.2						
			CO(c)	D.3						
			NOx(c	D.4						
			HC(h)	D.6						

TOTALS

TOTALS $\sum$ Subgroups	Work Trip Start-Up Emissions (grams)	+	$\sum$ Subgroups	Non-Work Trip Start-Up Emissions (grams)	=	Total Start-Up Emissions (grams)
HC	6,940,000		HC	22,394,000		29,334,000
CO	82,541,000		CO	218,307,000		300,848,000
NOx	1,180,000		NOx	4,256,000		5,436,000

---

[1] Source Worksheets are indicated in parentheses where applicable

[2] (c) indicates cold start factor

(h) indicates hot soak factor

[3] both work and non-work start-up factors obtained from the indicated tables

VI-D. AUTO TRAVEL EMISSIONS

☒ Base Alternative

☐ Revised Alternative

Policy: Areawide Traffic Engineering

Forecast Year: 1982

	Work Trips				Non-Work Trips			
(1) Population Subgroup	(2) Average Speed	(3) VMT (VI-A)[1]	(4) Auto Travel Factors (Table D.7)	(5) Emissions = Col. 3 X Col. 4 (grams)	(6) Average Speed	(7) VMT (VI-A)	(8) Auto Travel Factors (Table D.7)	(9) Emissions = Col. 7 X Col. 8 (grams)
All	23.3	5,030,000	HC 1.7	8,551,000	25.2	8,529,000	HC 1.6	13,646,000
			CO 26.0	130,780,000			CO 24.1	205,549,000
			NOx 2.0	10,060,000			NOx 2.1	17,911,000
			HC				HC	
			CO				CO	
			NOx				NOx	
			HC				HC	
			CO				CO	
			NOx				NOx	
			HC				HC	
			CO				CO	
			NOx				NOx	
			HC				HC	
			CO				CO	
			NOx				NOx	
			HC				HC	
			CO				CO	
			NOx				NOx	

TOTALS	Work Trip Travel Emissions (grams) $\sum_{\text{Subgroups}}$	+	Non-Work Trip Travel Emissions (grams) $\sum_{\text{Subgroups}}$	=	Total VMT Travel Emissions (grams)
HC	8,551,000		13,646,000		22,197,000
CO	130,780,000		205,549,000		336,329,000
NOx	10,060,000		17,911,000		27,971,000

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[1] Source Worksheets are indicated in parentheses where applicable

VI-D. AUTO TRAVEL EMISSIONS

☐ Base Alternative

☒ Revised Alternative

Policy: Areawide Traffic Engineering

Forecast Year: 1982

	Work Trips				Non-Work Trips			
(1) Population Subgroup	(2) Average Speed	(3) VMT (VI-A)[1]	(4) Auto Travel Factors (Table D.7)	(5) Emissions = Col. 3 X Col. 4 (grams)	(6) Average Speed	(7) VMT (VI-A)	(8) Auto Travel Factors (Table D.7)	(9) Emissions = Col. 7 X Col. 8 (grams)
All	26.5	5,036,000	HC 1.48	7,453,000	28.5	8,674,000	HC 1.36	11,797,000
			CO 22.86	115,123,000			CO 21.10	183,021,000
			NOx 2.14	10,777,000			NOx 2.24	19,430,000
			HC				HC	
			CO				CO	
			NOx				NOx	
			HC				HC	
			CO				CO	
			NOx				NOx	
			HC				HC	
			CO				CO	
			NOx				NOx	
			HC				HC	
			CO				CO	
			NOx				NOx	
			HC				HC	
			CO				CO	
			NOx				NOx	

TOTALS		Work Trip Travel Emissions (grams)			Non-Work Trip Travel Emissions (grams)		Total VMT Travel Emissions (grams)
$\sum$ Subgroups	HC	7,453,000	+	$\sum$ Subgroups	11,797,000	=	19,250,000
	CO	115,123,000			183,021,000		298,144,000
	NOx	10,777,000			19,430,000		30,207,000

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[1] Source Worksheets are indicated in parentheses where applicable

$$S = \frac{60}{t}$$

where:

s = travel speed in miles per hour

t = travel time rate in minutes per mile

The revised alternative travel speed is calculated by applying the proportional changes in travel time for work and non-work travel shown in Table VII-10 to the base case travel time rates from step 6 to determine the revised average travel time rate. These rates are then converted to average travel speeds using the above formula.

The 1982 analysis year and the average travel speeds calculated are used to enter Table D.6 for the base and revised cases and for work and non-work travel. Linear interpolation is required to determine the emissions factors for each pollutant. The VMT figures from Worksheet VI-A complete the input data for Worksheet VI-D.

Finally, Worksheet VI-E is used to summarize the total vehicle emissions for the base and revised cases, and to calculate the percentage change in emissions for each pollutant.

H. Interpretation of Results

As Worksheet VI-E shows, the improved travel speeds associated with the proposed traffic engineering measures outweigh the associated increase in VMT in determining HC and CO emissions impacts. Meaningful reductions in the production of these pollutants are predicted, while NO_x emissions are predicted to increase.

While the emissions impacts calculated in this example provide a reliable sense of the order of magnitude of the influence of traffic engineering actions, several relatively simple changes in the analysis

VI-E. SUMMARY OF CHANGES IN EMISSIONS

Revised Alternative

Policy: Areawide Traffic Engineering

Forecast Year: 1982

(1) Population Subgroup		Base Emissions			Revised Emissions			(8) Change in Total Emissions (Col. 4-Col. 7)	(9) Percent Change in Emissions (Col. 8/Col4) x 100
		(2) Trip-Related (VI-C)[1]	(3) Travel (VI-D)	(4) Total (Col.2 + Col.3)	(5) Trip-Related (VI-C)	(6) Travel (VI-D)	(7) Total (Col.5+Col.6)		
	HC	28,962,000	22,197,000	51,159,000	29,334,000	19,250,000	48,584,000	- 2,575,000	-5.0%
	CO	297,093,000	336,329,000	633,422,000	300,848,000	298,144,000	598,992,000	-34,430,000	-5.4%
	NOx	5,363,000	27,971,000	33,334,000	5,436,000	30,207,000	35,643,000	+2,309,000	+6.9%
	HC								
	CO								
	NOx								
	HC								
	CO								
	NOx								
	HC								
	CO								
	NO_x								

TOTALS

∑ Sub-groups	Total Base Emissions (grams)
HC	
CO	
NOx	

∑ Sub-groups	Total Change in Emissions (grams)	Percent Change, Total Emissions
HC	- 2,575,000	-5.0%
CO	-34,430,000	-5.4%
NOx	+ 2,309,000	+6.9%

---

[1] Source Worksheets are indicated in parentheses where applicable

could improve the estimates. For example, separately calculating the change in auto emissions accounted for by travel on each of the highway functional classes, rather than the aggregate average emissions rates for all facilities in the urban area would provide a more accurate air quality impact estimate. This extra accuracy would be useful in comparing the proposed traffic engineering actions with other transportation measures which may be competing for limited funding.

The positive impact of the traffic engineering measures on both auto emissions and fuel consumption in the region (see Worksheet VI-E and Table VII-10) indicate that they are quite desirable. The next step in the planning process would be the identification of specific highway facilities which would benefit from these measures and the development of cost estimates for their implementation. Once specific opportunities have been identified, computer analysis techniques such as TRANSYT and FREQ would be applied for detailed planning purposes.

*U.S. GOVERNMENT PRINTING OFFICE : 1980 0-311-726/3706